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EVALUATION OF MUNICIPAL SEWAGE TREATMENT ALTERNATIVES

BATTELLE-PACIFIC NORTHWEST LABORATORIES

PREPARED FOR
COUNCIL OF ENVIRONMENTAL QUALITY

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A comparison of alternative waste water treatment strategies, including the costs and environmental effects. Available municipal waste water and sludge treatment processes were selected on the basis of current or projected use in various sized flow regimes. Each set of liquid treatment strategies and sludge options was characterized as to resource input requirements and subsequent outputs.

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FINAL REPORT

EVALUATION OF MUNICIPAL SEWAGE TREATMENT ALTERNATIVES

COUNCIL ON ENVIRONMENTAL QUALITY
EXECUTIVE OFFICE OF THE PRESIDENT
IN ASSOCIATION WITH THE
ENVIRONMENTAL PROTECTION AGENCY

CONTRACT EQC 316

FEBRUARY 1974

PACIFIC NORTHWEST LABORATORIES
a division of
BATTELLE MEMORIAL INSTITUTE
P.O. Box 999
Richland, Washington 99352

1a

USER'S GUIDE

The purpose of this report is to provide a single document which can be utilized, on a comparative basis, to develop preliminary selections of appropriate wastewater treatment schemes for a municipality. The format of the text allows the reader to compare various treatment strategies on an energy, environmental, or economic basis and to develop cost figures which may better reflect a particular local situation.

The user of this text should utilize the procedure outlined below in order to develop a proper understanding of the basis of the report and to facilitate treatment system comparisons.

- Review the Introduction chapter in order to become familiar with the treatment strategies and sludge handling options chosen for study within the text.

- Review the Summary section in order to develop an understanding of the general patterns which exist in the information presented in the profile sheets. Systems are compared on a relative basis in this section.

- Review the Liquid Treatment Strategies and Sludge Disposal Options section to obtain a narrative description of the treatment options and a discussion of the limitations of each strategy.

- Review the Treatment and Disposal Process Profile section in order to develop an understanding of the profile sheet format and meaning. This section contains detailed data on the input and output characteristics of the systems studied.

- Review Appendices A and B to understand the specific theory behind design of each treatment operation and the specific assumptions utilized for each unit operation, process, or sludge handling option in this study.

- With the preceding information in mind, compare the viable alternatives which appear to apply by utilizing the process profile sheets.

- To develop cost figures more representative of a particular municipality, utilize the worksheets in conjunction with Appendices A and B and the profile sheets.

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INTRODUCTION

The Federal Water Pollution Control Act Amendments of 1972 require all federal grant applicants to demonstrate that alternative waste treatment strategies have been evaluated prior to final selection of a waste treatment scheme. Regardless of the legislative directive, it is clearly advisable that such a review be made before plans for new treatment facilities or expansions of old treatment plants are undertaken. A proper evaluation can aid in minimizing total costs, and optimizing the allocation of resources. The latter point is of great interest since the effluent of the municipal waste treatment plant is coming to be recognized as a potential resource in its own right.

Although much of the information necessary to evaluate alternative waste management strategies exists in published and unpublished forms, no single comprehensive source which gathers together the required information has been available previously. Such a comprehensive source which outlines the costs and environmental effects of alternative treatment strategies should be invaluable to Federal policymakers and to local communities faced with the problem of selecting optimum treatment systems for particular situations.

In order to provide such a source document, the Council on Environmental Quality initiated the study reported herein. Available municipal wastewater and sludge treatment processes were selected for study on the basis of current or projected use in various sized flow regimes. Each set of liquid treatment strategies and concomitant sludge options were characterized as to resource input requirements and subsequent outputs. The profiles thus constructed formed the basis for a comprehensive evaluation of the alternatives aimed at selection of optimal courses of action.

Such a selection process requires more than a simple objective comparison. Some parameters cannot be quantified and many are not easily defined in dollar values. Hence, subjective decisions must be included to evaluate items such as nuisance generation from noise and odor and the social cost of discharges of various pollutants.

The selection process is further complicated by the complex environment within which a treatment plant may be placed. Clearly, certain strategies while optimal under a given set of circumstances may be undesirable in a somewhat different situation, e.g., biological treatment options may be the least cost alternative for typical domestic plants but may be unacceptable in areas where frequent toxic industrial discharges occur or where mean temperatures are typically below freezing. This suggests that alternatives must be characterized both under normal operating conditions and in terms of their sensitivity to envrionmental changes.

The data contained in this report are intended for use in alternative strategy selection rather than for facility design. Thus, it is more useful in a comparative sense than in an absolute one. Accurate estimates of costs and required operating conditions will vary with specific applications. Whereas the work sheets at the end of the report should aid in improving estimates based on land value and distance considerations, only detailed design work can provide solid cost and design estimates for a specific facility. The data presented here represent the best available information which could be obtained.

It must be recognized that the evaluation of waste treatment approaches by a municipality will not be governed by technical considerations alone. Indeed, some bias is introduced into the selection process by existing legislative and institutional structures. A survey of the Federal Water Pollution Control Act Amendments of 1972 and other related laws revealed that the present Federal grant and bonding mechanisms strongly favor use of capital intensive technology. This emphasis is coupled with some very clear directives to utilize land application techniques when possible. The combination of the two influences is quite strong now that land costs are eligible for grant aid.

These and other non-technical factors must be considered during the selection process in that they can have major effects on the cost to the municipality of a project.

The liquid treatment strategies selected for study in this program are shown in Figures 1-9 as conceptual flowsheets accompanied by a brief narrative. Similar characterizations of the sludge disposal options evaluated in the program are presented in Figures 10-21.

The following section of this report contains a summary of the findings of this program together with graphical comparisons of the inputs and outputs required by the alternatives evaluated. This section is followed by descriptions of the actual unit processes and disposal options themselves and the basic assumptions employed in deriving the required data. The heart of the document consists of detailed information sheets or profiles presenting the quantitative data collected during an intensive study of treatment processes. The final section of the text addresses cost considerations and provides sample calculations for modifying cost parameters to reflect variations from the assumptions made in the current study.

Appended materials include detailed discussions of unit processes and sludge disposal options studied. Particular emphasis is placed on identifying strengths and weaknesses and describing the sensitivity of various process to changes in influent or environmental characteristics. Appendix C includes an extensive review of the agricultural aspects and value of land application processes.

The first strategy consists of primary treatment followed by land application of the effluent as illustrated below. Primary treatment is an effective unit process, but by itself is not capable of achieving the degree of treatment required to meet present water quality requirements. Consequently, effluent cannot be discharged directly to surface waters, but should be further treated through land application.

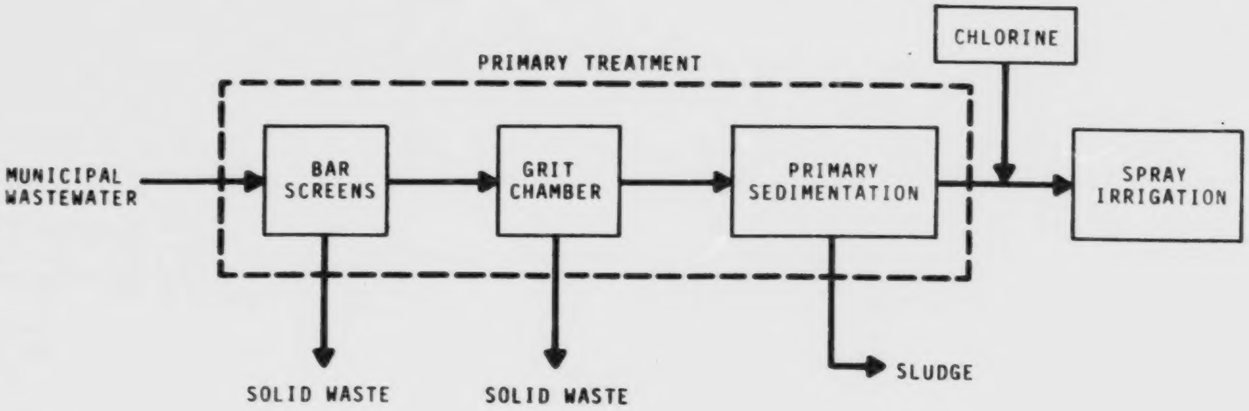
PRIMARY TREATMENT
CHLORINE
MUNICIPAL WASTEWATER
BAR SCREENS
GRIT CHAMBER
PRIMARY SEDIMENTATION
SPRAY IRRIGATION
SOLID WASTE
SOLID WASTE
SLUDGE

FIGURE 1. STRATEGY # 1: PRIMARY TREATMENT WITH LAND DISPOSAL OF LIQUID EFFLUENT

The second strategy consists of waste stabilization as shown below. Waste stabilization can be a very effective treatment technique capable of effluent quality sufficient for discharge either to land or to surface waters. The degree of treatment achieved is proportional to the size of the facility.

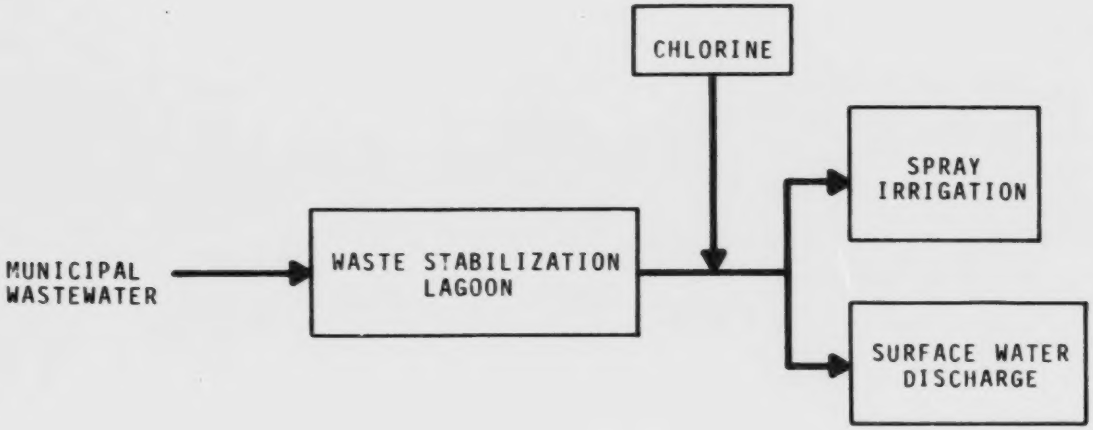
CHLORINE
MUNICIPAL WASTEWATER
WASTE STABILIZATION LAGOON
SPRAY IRRIGATION
SURFACE WATER DISCHARGE

FIGURE 2. STRATEGY # 2: WASTE STABILIZATION LAGOON

The third and fourth strategies, illustrated below, consist of primary and trickling filter treatment followed by discharge to surface water or land application, respectively. Trickling filters are employed by a great many municipalities of all sizes.

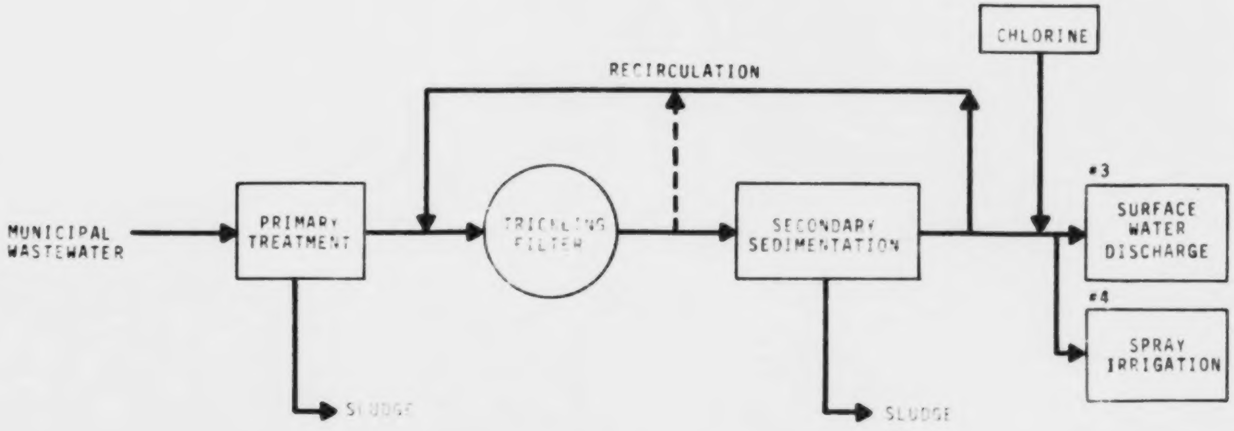
MUNICIPAL WASTEWATER
PRIMARY TREATMENT
SLUDGE
TRICKLING FILTER
RECIRCULATION
SECONDARY SEDIMENTATION
SLUDGE
CHLORINE
#3
SURFACE WATER DISCHARGE
#4
SPRAY IRRIGATION

FIGURE 3. STRATEGY # 3: TRICKLING FILTER WITH SURFACE WATER DISCHARGE
STRATEGY # 4: TRICKLING FILTER WITH LAND DISPOSAL

The fifth and sixth strategies consist of primary and activated sludge treatment followed by discharge to surface water and land application, respectively, as can be seen below. Activated sludge is presently the single most popular type of secondary treatment process being designed for municipalities. The complete mix activated sludge process was selected based on its ability to consistently achieve high quality effluents. Furthermore, it is presently considered to be the superior method of biological treatment consistent with present and future treatment requirements as set forth in the Federal Water Pollution Control Act Amendments of 1972.

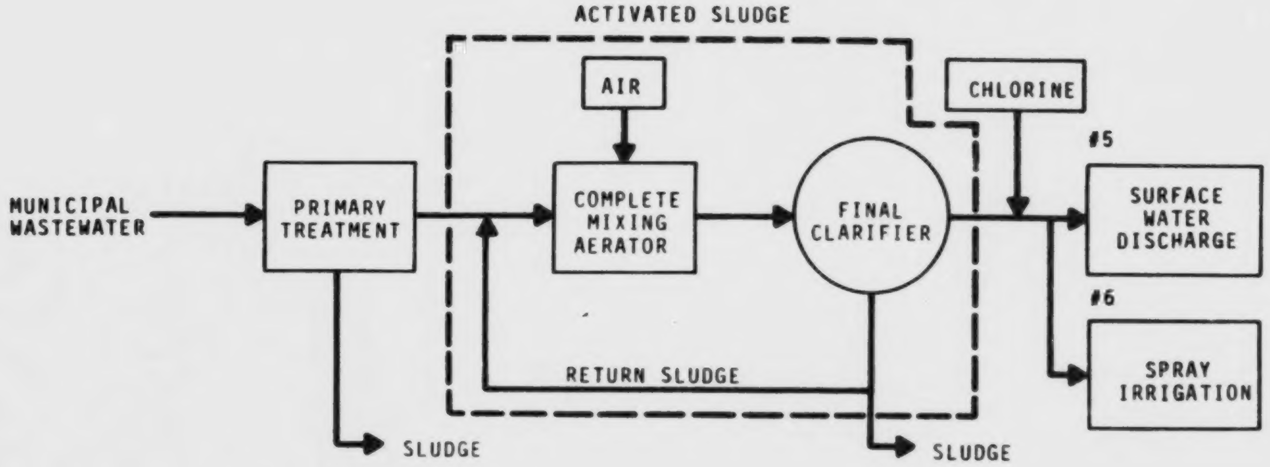
ACTIVATED SLUDGE
AIR
CHLORINE
#5
MUNICIPAL WASTEWATER
PRIMARY TREATMENT
COMPLETE MIXING AERATOR
FINAL CLARIFIER
SURFACE WATER DISCHARGE
#6
RETURN SLUDGE
SPRAY IRRIGATION
SLUDGE
SLUDGE

FIGURE 4. STRATEGY # 5: ACTIVATED SLUDGE WITH SURFACE WATER DISCHARGE
STRATEGY # 6: ACTIVATED SLUDGE WITH LAND DISPOSAL

The seventh strategy consists of activated sludge treatment with alum addition and nitrification-denitrification followed by discharge to surface water as illustrated below. Land application of effluent water is not considered for this treatment sequence since nutrient removal would be superfluous if that mode of discharge were utilized. The nutrient removal capacity is presumably added to protect surface waters to which intended discharges are to be made.

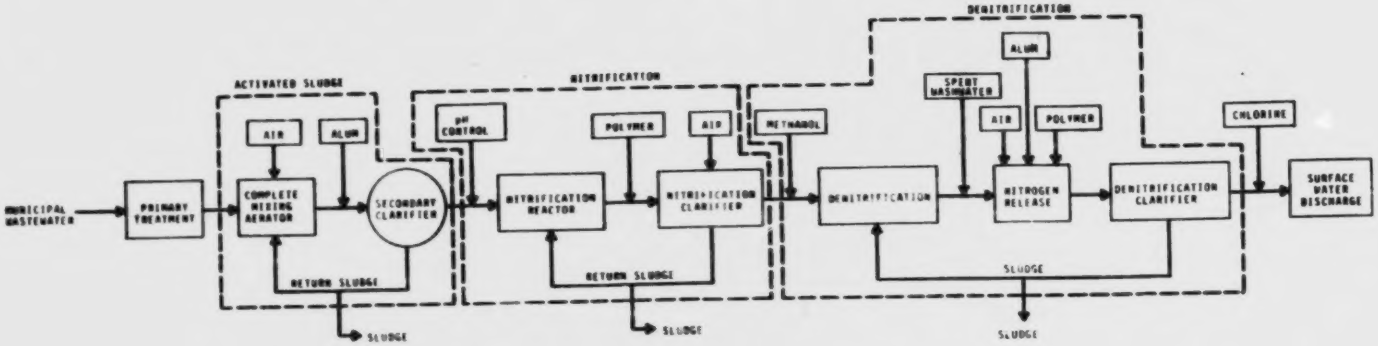
MUNICIPAL WASTEWATER
PRIMARY TREATMENT
ACTIVATED SLUDGE
AIR
ALUM
COMPLETE MIXING AERATOR
SECONDARY CLARIFIER
RETURN SLUDGE
SLUDGE
NITRIFICATION
pH CONTROL
POLYMER
AIR
NITRIFICATION REACTOR
NITRIFICATION CLARIFIER
RETURN SLUDGE
SLUDGE
DENITRIFICATION
METHANOL
SPENT WASHWATER
ALUM
AIR
POLYMER
DENITRIFICATION
NITROGEN RELEASE
DENITRIFICATION CLARIFIER
SLUDGE
SLUDGE
CHLORINE
SURFACE WATER DISCHARGE

FIGURE 5. STRATEGY # 7: BIOLOGICAL-CHEMICAL TREATMENT

The eighth strategy consists of activated sludge treatment and coagulation-filtration followed by discharge to surface waters as depicted below. Once again, land application was not considered as an ultimate disposal option since its use would preclude the necessity for the high level of treatment afforded by the addition of coagulation-filtration.

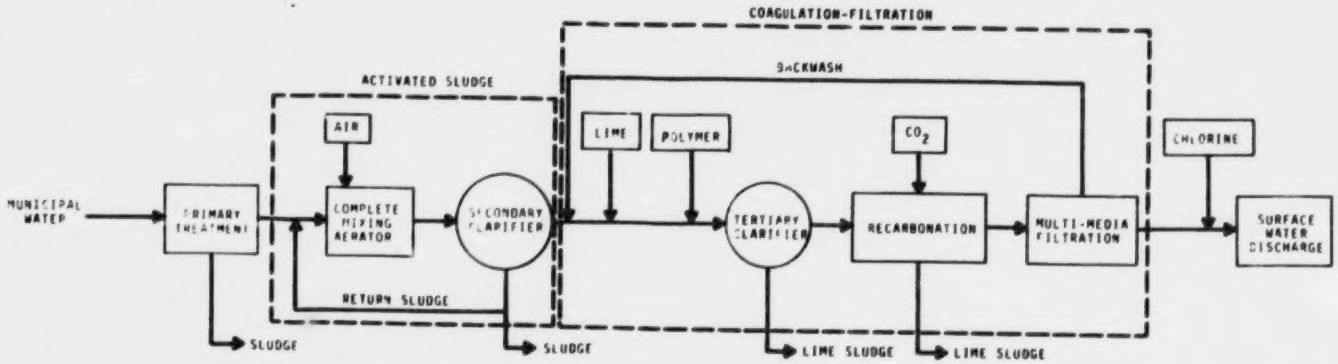
MUNICIPAL WATER
PRIMARY TREATMENT
SLUDGE
ACTIVATED SLUDGE
AIR
COMPLETE MIXING AERATOR
SECONDARY CLARIFIER
RETURN SLUDGE
SLUDGE
COAGULATION-FILTRATION
BACKWASH
LIME
POLYMER
TERTIARY CLARIFIER
LIME SLUDGE
CO2
RECARBONATION
LIME SLUDGE
MULTI-MEDIA FILTRATION
CHLORINE
SURFACE WATER DISCHARGE

FIGURE 6. STRATEGY # 8: ACTIVATED SLUDGE-COAGULATION-FILTRATION

The ninth strategy consists of activated sludge, coagulation-filtration, carbon sorption, and zeolite ammonia removal followed by discharge to surface waters as outlined below.

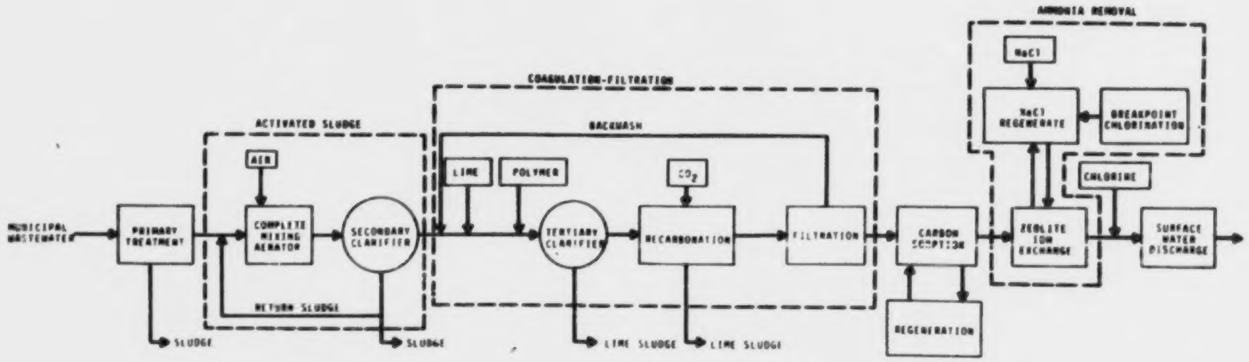
MUNICIPAL WASTEWATER
PRIMARY TREATMENT
SLUDGE
ACTIVATED SLUDGE
AIR
COMPLETE MIXING AERATOR
SECONDARY CLARIFIER
RETURN SLUDGE
SLUDGE
COAGULATION-FILTRATION
BACKWASH
LIME
POLYMER
TERTIARY CLARIFIER
LIME SLUDGE
CO_2
RECARBONATION
LIME SLUDGE
FILTRATION
CARBON SORPTION
REGENERATION
AMMONIA REMOVAL
NaCl
NaCl REGENERATE
BREAKPOINT CHLORINATION
ZEOLITE ION EXCHANGE
CHLORINE
SURFACE WATER DISCHARGE

FIGURE 7. STRATEGY # 9: TERTIARY TREATMENT

The tenth strategy consists of coagulation-filtration and carbon adsorption followed by discharge to surface waters as illustrated below. This physical-chemical treatment scheme produces high quality water which can be returned to surface waters.

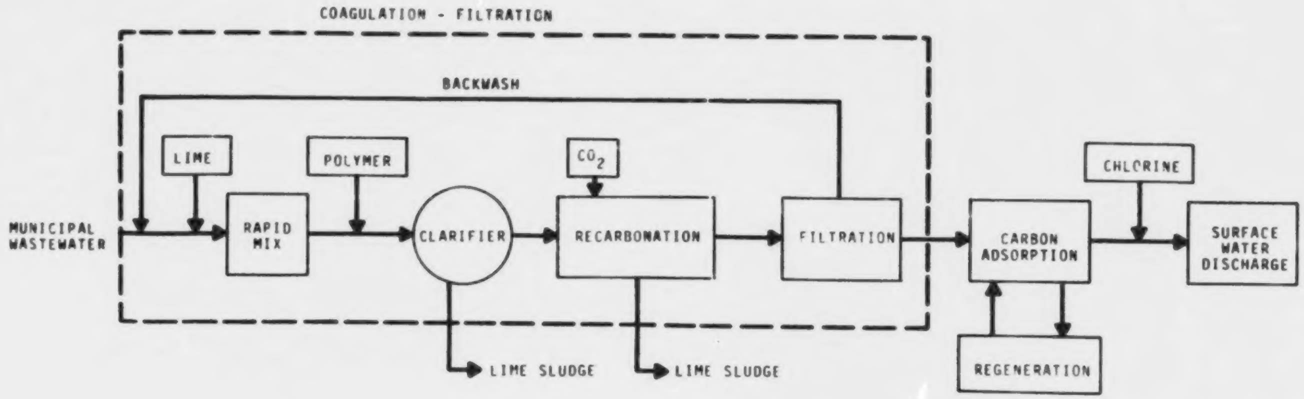
COAGULATION - FILTRATION
BACKWASH
MUNICIPAL WASTEWATER
LIME
RAPID MIX
POLYMER
CLARIFIER
CO_2
RECARBONATION
FILTRATION
LIME SLUDGE
LIME SLUDGE
CARBON ADSORPTION
REGENERATION
CHLORINE
SURFACE WATER DISCHARGE

FIGURE 8. STRATEGY # 10: PHYSICAL-CHEMICAL TREATMENT

The eleventh and final strategy evaluated consists of extended aeration followed by surface water discharge of liquid effluents as illustrated below. Extended aeration can provide relatively high quality water if properly designed and hence effluents may be disinfected and released to surface water without further treatment.

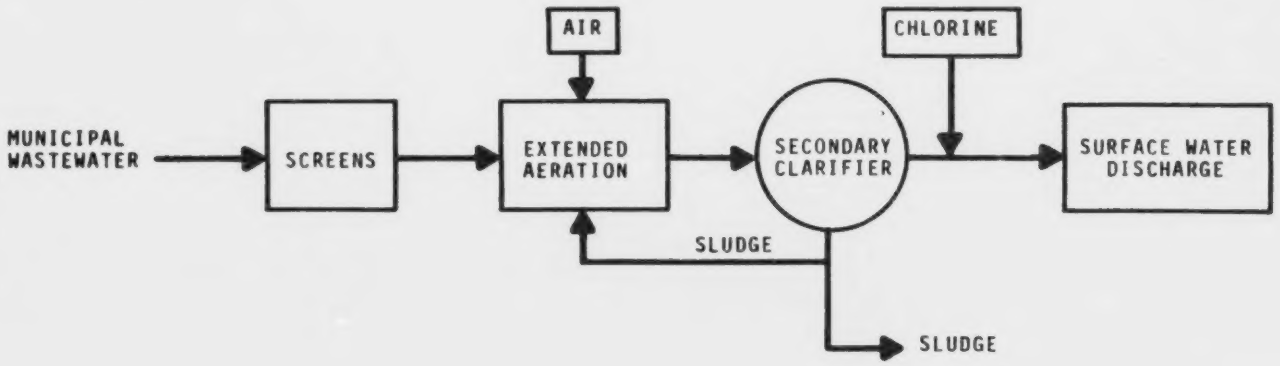
MUNICIPAL WASTEWATER
SCREENS
AIR
EXTENDED AERATION
SECONDARY CLARIFIER
CHLORINE
SURFACE WATER DISCHARGE
SLUDGE
SLUDGE

FIGURE 9. STRATEGY # 11: EXTENDED AERATION

A schematic diagram of sludge option one is presented below. The overall sludge handling system, depending upon plant size, can be operated intermittently or continuously. Sludge is removed from the clarifiers, thickened by gravity or air flotation (depending upon sludge type) with the thickener overflow being recycled to the head end of the plant, conditioned by the utilization of polymers (if such treatment is appropriate), dewatered by vacuum filtration including filtrate recycle to the plant influent, incinerated in a multiple hearth unit, and disposed of in a sanitary landfill.

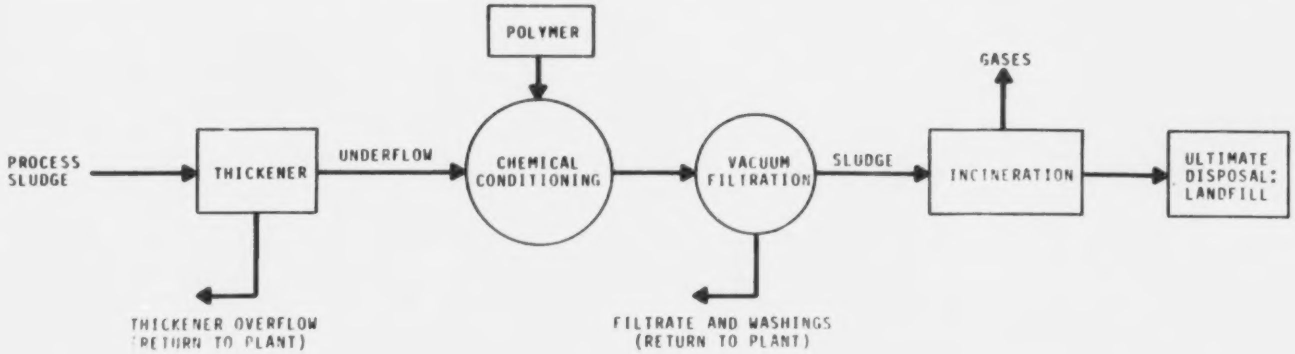
POLYMER
GASES
PROCESS SLUDGE
THICKENER
UNDERFLOW
CHEMICAL CONDITIONING
VACUUM FILTRATION
SLUDGE
INCINERATION
ULTIMATE DISPOSAL: LANDFILL
THICKENER OVERFLOW (RETURN TO PLANT)
FILTRATE AND WASHINGS (RETURN TO PLANT)

FIGURE 10. SLUDGE OPTION 1: SLUDGE THICKENING, CHEMICAL CONDITIONING, VACUUM FILTRATION, INCINERATION, AND LANDFILL

Below is a schematic diagram of the second sludge handling system. Incoming sludge from the clarifiers and treatment systems is conditioned by a polymer, dewatered by centrifuge with the centrate being recycled to the plant's head end, incinerated in a multiple hearth incinerator, and disposed of at a sanitary landfill. The process can be operated continuously or intermittently.

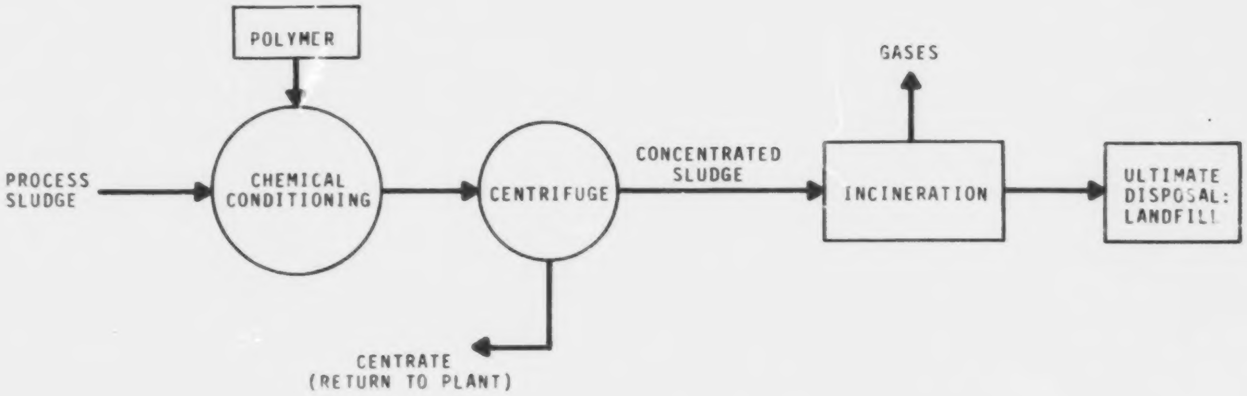
POLYMER
GASES
PROCESS SLUDGE
CHEMICAL CONDITIONING
CENTRIFUGE
CONCENTRATED SLUDGE
INCINERATION
ULTIMATE DISPOSAL: LANDFILL
CENTRATE (RETURN TO PLANT)

FIGURE 11. SLUDGE OPTION 2: CHEMICAL CONDITIONING, CENTRIFUGE DEWATERING, INCINERATION, AND LANDFILL

Sludge option three is represented schematically below. Initially, the sludge is thickened and the overflow is returned to the plant. Then the sludge is heat treated in the porteous unit with the portrate being recycled to the plant influent. The sludge, with improved dewatering characteristics, is then passed to a vacuum filter where the filtrate is also returned to the plant influent and the cake is transported to the incinerator where the final product is an inert ash which is disposed of in a sanitary landfill.

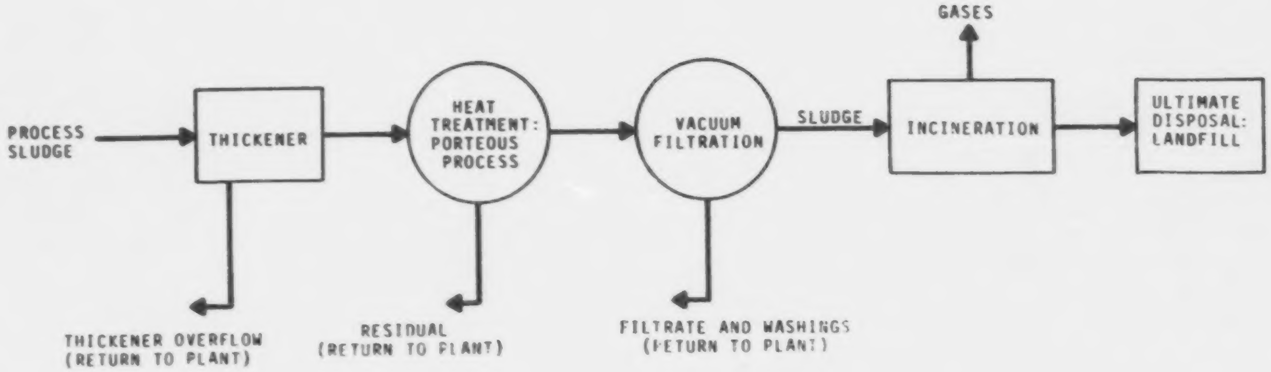
GASES
PROCESS SLUDGE
THICKENER
HEAT TREATMENT: PORTEOUS PROCESS
VACUUM FILTRATION
SLUDGE
INCINERATION
ULTIMATE DISPOSAL: LANDFILL
THICKENER OVERFLOW (RETURN TO PLANT)
RESIDUAL (RETURN TO PLANT)
FILTRATE AND WASHINGS (RETURN TO PLANT)

FIGURE 12. SLUDGE OPTION 3: SLUDGE THICKENING, CONDITIONING BY HEAT TREATMENT, VACUUM FILTRATION, INCINERATION, AND LANDFILL

Sludge option number four is represented schematically below. In this case, sludge from the treatment system is initially thickened with the thickener overflow being returned to the plant. The thickened sludge is anaerobically digested and applied to a sand drying bed. After completion of the drying process, the sludge is removed and hauled to a sanitary landfill site.

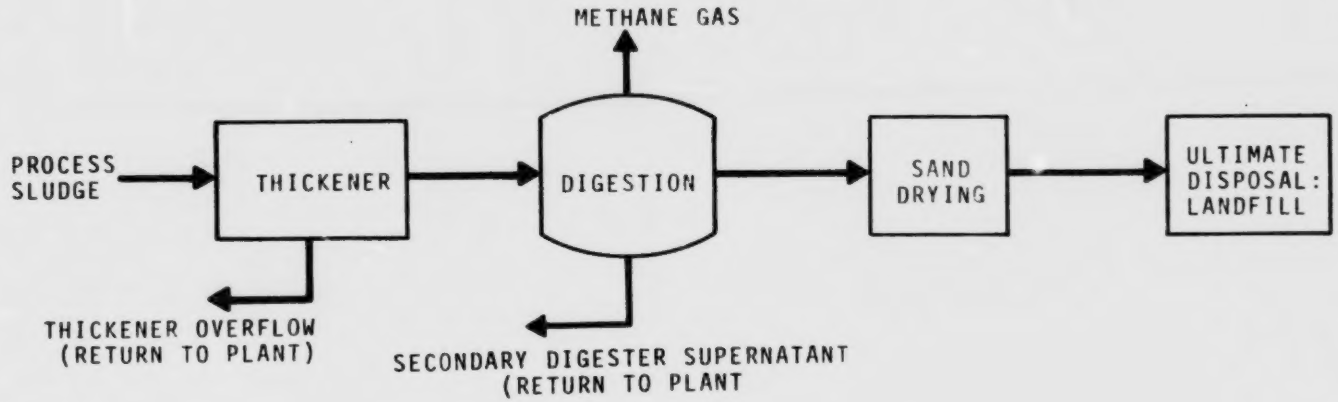
METHANE GAS
PROCESS SLUDGE
THICKENER
DIGESTION
SAND DRYING
ULTIMATE DISPOSAL: LANDFILL
THICKENER OVERFLOW (RETURN TO PLANT)
SECONDARY DIGESTER SUPERNATANT (RETURN TO PLANT

FIGURE 13. SLUDGE OPTION 4: SLUDGE THICKENING, DIGESTION, SAND DRYING BEDS, AND LANDFILL

Sludge option five is schematically represented below. Sludge is collected from the wastewater treatment system, thickened with the overflow being recycled to the plant influent, digested anaerobically and transported to a designated region for land spreading.

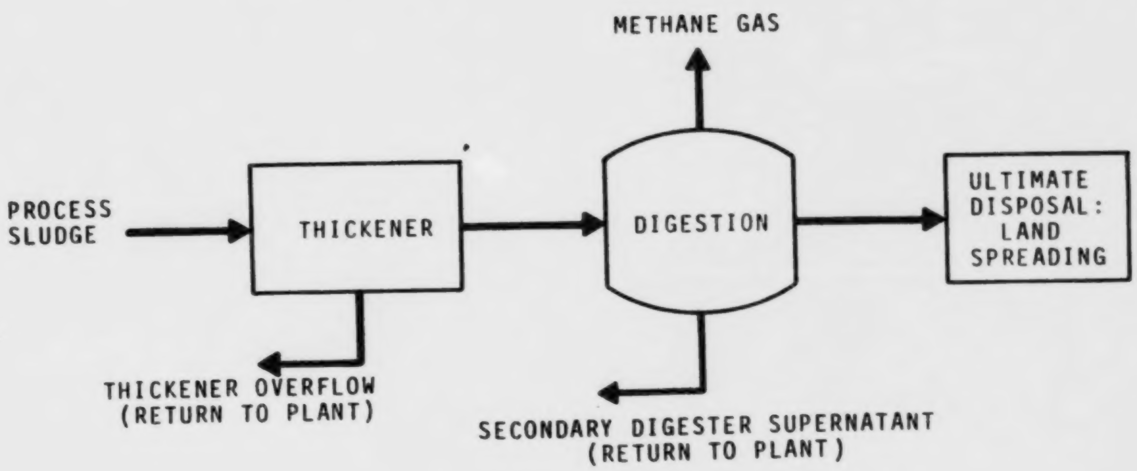
METHANE GAS
PROCESS SLUDGE
THICKENER
DIGESTION
ULTIMATE DISPOSAL: LAND SPREADING
THICKENER OVERFLOW (RETURN TO PLANT)
SECONDARY DIGESTER SUPERNATANT (RETURN TO PLANT)

FIGURE 14. SLUDGE OPTION 5: SLUDGE THICKENING, DIGESTION, AND LAND SPREADING

Sludge option number six is represented schematically below. In this, sludge is collected from the various wastewater treatment systems, thickened by gravity or air flotation methods (depending upon the sludge characteristics), anaerobically digested for pathogen and odor control, and transported to the ocean by pipeline.

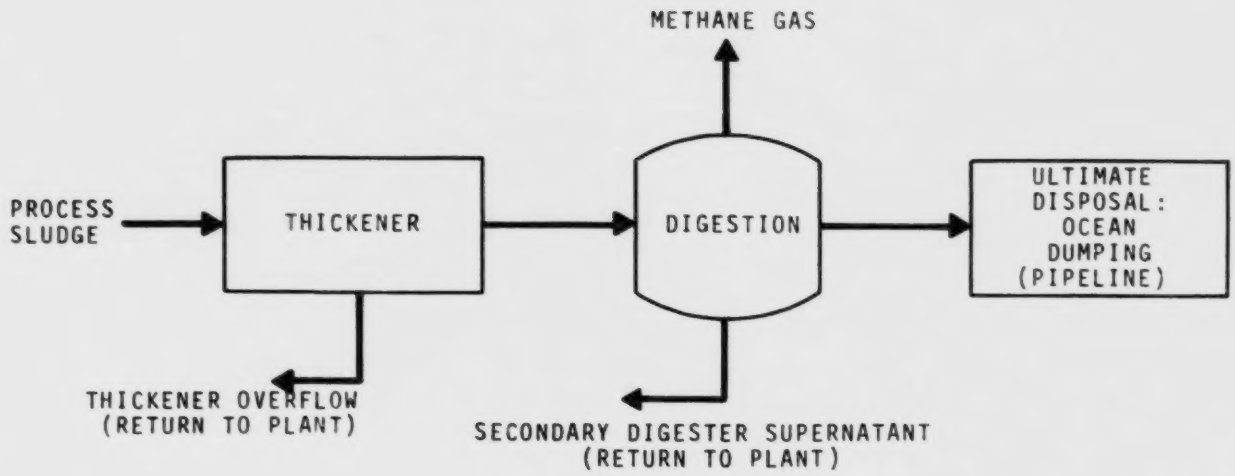
METHANE GAS
PROCESS SLUDGE
THICKENER
DIGESTION
ULTIMATE DISPOSAL: OCEAN DUMPING (PIPELINE)
THICKENER OVERFLOW (RETURN TO PLANT)
SECONDARY DIGESTER SUPERNATANT (RETURN TO PLANT)

FIGURE 15. SLUDGE OPTION 6: SLUDGE THICKENING, DIGESTION, AND OCEAN DUMPING BY PIPELINE

A schematic representation of sludge option number seven is shown below. Sludge is collected and thickened by an appropriate method, anaerobically digested, and dewatered with a vacuum filter. Thickener overflow and filtrate are recycled to the plant influent. The filter cake is disposed of in a sanitary landfill after hauling by truck.

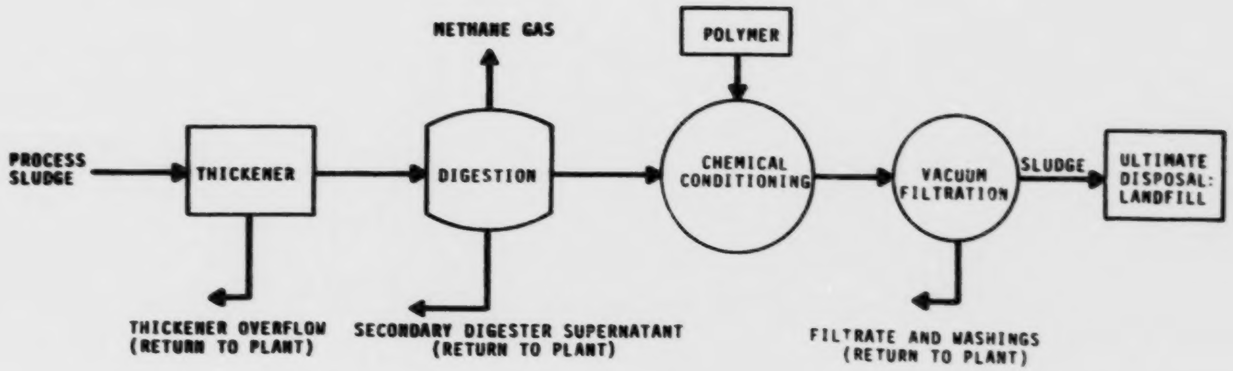
PROCESS SLUDGE
THICKENER
THICKENER OVERFLOW (RETURN TO PLANT)
METHANE GAS
DIGESTION
SECONDARY DIGESTER SUPERNATANT (RETURN TO PLANT)
POLYMER
CHEMICAL CONDITIONING
VACUUM FILTRATION
FILTRATE AND WASHINGS (RETURN TO PLANT)
SLUDGE
ULTIMATE DISPOSAL: LANDFILL

FIGURE 16. SLUDGE OPTION 7: SLUDGE THICKENING, DIGESTION, CHEMICAL CONDITIONING, VACUUM FILTRATION, AND LANDFILL

The eighth sludge option is represented schematically below. Sludges collected from the various treatment schemes considered are combined and depending on the type of sludge are gravity or air flotation thickened. Thickened sludge is then passed through an anaerobic digester for pathogen and odor control. Sludge exiting from the preceding process is vacuum filtered with the filtrate being returned to the plant's head end.

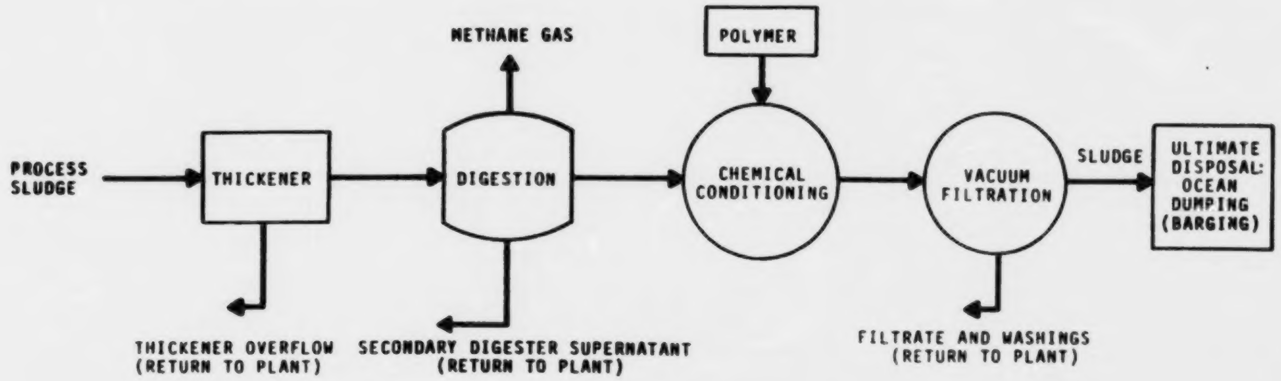
PROCESS SLUDGE
THICKENER
DIGESTION
METHANE GAS
POLYMER
CHEMICAL CONDITIONING
VACUUM FILTRATION
SLUDGE
ULTIMATE DISPOSAL: OCEAN DUMPING (BARGING)
THICKENER OVERFLOW (RETURN TO PLANT)
SECONDARY DIGESTER SUPERNATANT (RETURN TO PLANT)
FILTRATE AND WASHINGS (RETURN TO PLANT)

FIGURE 17. SLUDGE OPTION 8: SLUDGE THICKENING, DIGESTION, CHEMICAL CONDITIONING, VACUUM FILTRATION, AND OCEAN DUMPING BY BARGING

A schematic diagram of chemical sludge option nine which involves gravity thickening, vacuum filtration, incineration, and sanitary landfill appears below. The lime sludge is gravity thickened with the overflow being recycled to the plant influent. The thickened sludge is vacuum filtered with the filtrate also recycled to the plant influent. The cake is then incinerated and the lime and ash are disposed of in a sanitary landfill.

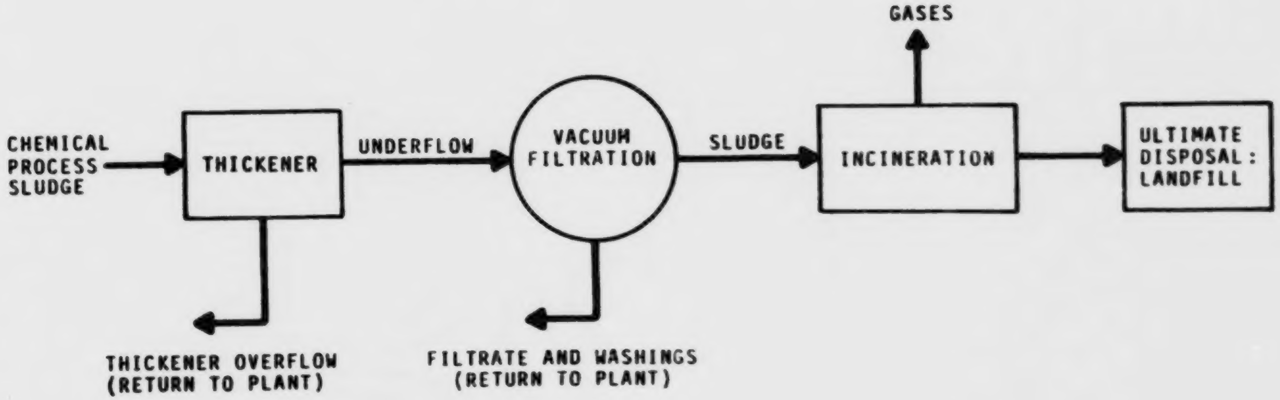
GASES
CHEMICAL PROCESS SLUDGE
THICKENER
UNDERFLOW
VACUUM FILTRATION
SLUDGE
INCINERATION
ULTIMATE DISPOSAL: LANDFILL
THICKENER OVERFLOW (RETURN TO PLANT)
FILTRATE AND WASHINGS (RETURN TO PLANT)

FIGURE 18. SLUDGE OPTION 9: CHEMICAL SLUDGE THICKENING, VACUUM FILTRATION, INCINERATION, AND LANDFILL

Sludge option ten, shown below, consists of gravity thickening, vacuum filtration, recalcination, lime reuse and landfill of recalciner blowdown. The chemical sludge is gravity thickened (recycling the overflow to the influent), vacuum filtered (with the filtrate being recycled), and recalcined in a multiple hearth incinerator. The lime is recycled for its value as a chemical coagulant. Approximately thirty percent (by weight) is wasted and disposed of in a sanitary landfill.

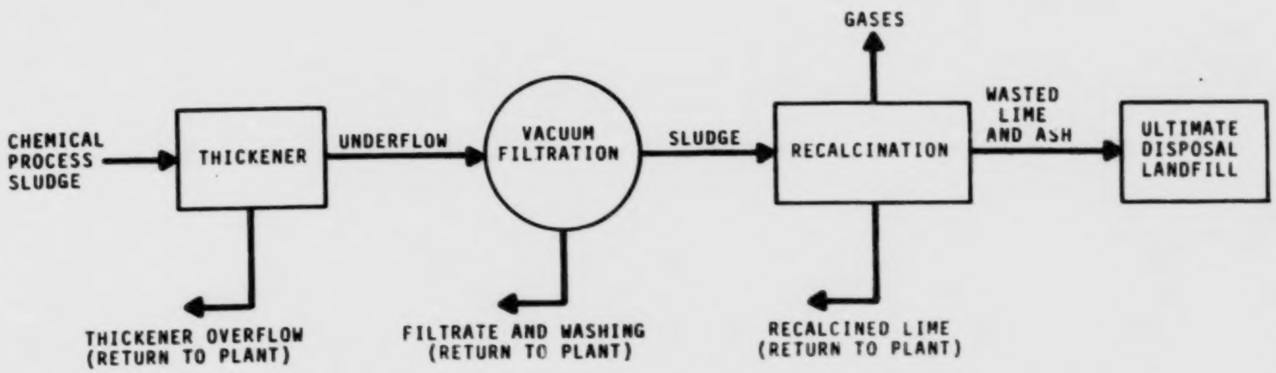
CHEMICAL PROCESS SLUDGE
THICKENER
UNDERFLOW
VACUUM FILTRATION
SLUDGE
RECALCINATION
GASES
WASTED LIME AND ASH
ULTIMATE DISPOSAL LANDFILL
THICKENER OVERFLOW (RETURN TO PLANT)
FILTRATE AND WASHING (RETURN TO PLANT)
RECALCINED LIME (RETURN TO PLANT)

FIGURE 19. SLUDGE OPTION 10: CHEMICAL SLUDGE THICKENING, VACUUM FILTRATION, RECALCINATION AND REUSE, AND LANDFILL OF WASTED RESIDUE

Sludge option eleven consists of gravity thickening, centrifugation, incineration, and sanitary landfill as represented by the schematic diagram below. Lime sludges are collected from the wastewater treatment systems, thickened by gravity (recycling the overflow), dewatered by centrifugation (recycling the centrate), incinerated in a multiple hearth unit and disposed of at a sanitary landfill site.

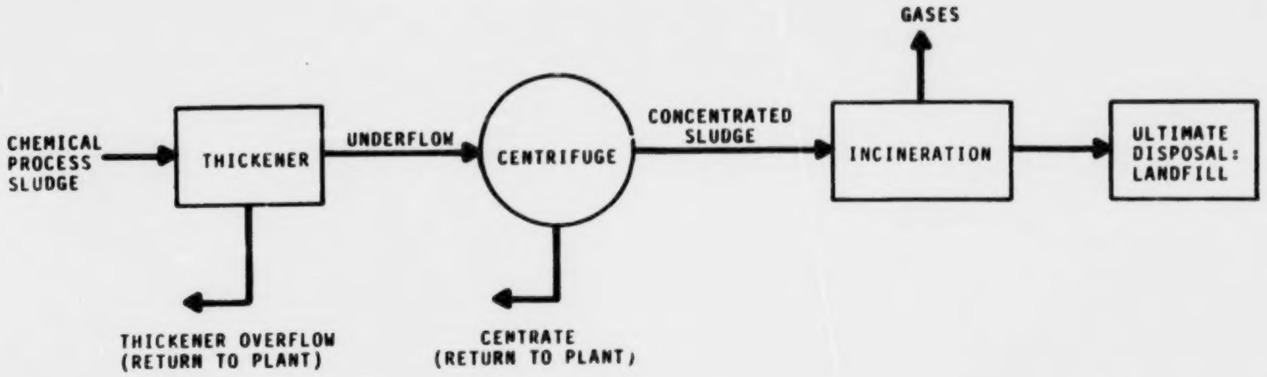
CHEMICAL PROCESS SLUDGE
THICKENER
UNDERFLOW
CENTRIFUGE
CONCENTRATED SLUDGE
GASES
INCINERATION
ULTIMATE DISPOSAL: LANDFILL
THICKENER OVERFLOW (RETURN TO PLANT)
CENTRATE (RETURN TO PLANT)

FIGURE 20. SLUDGE OPTION 11: CHEMICAL SLUDGE THICKENING, CENTRIFUGE DEWATERING, INCINERATION, AND LANDFILL

The final sludge option is represented schematically below. The chemical sludges are gravity thickened and the overflow is recycled to the plant influent. The thickened sludge is dewatered by centrifuge with the centrate recycled to the plant. The dewatered cake is recalcined in multiple hearth unit to recover the lime for reuse. Thirty percent of the recalcined lime is wasted to a sanitary landfill.

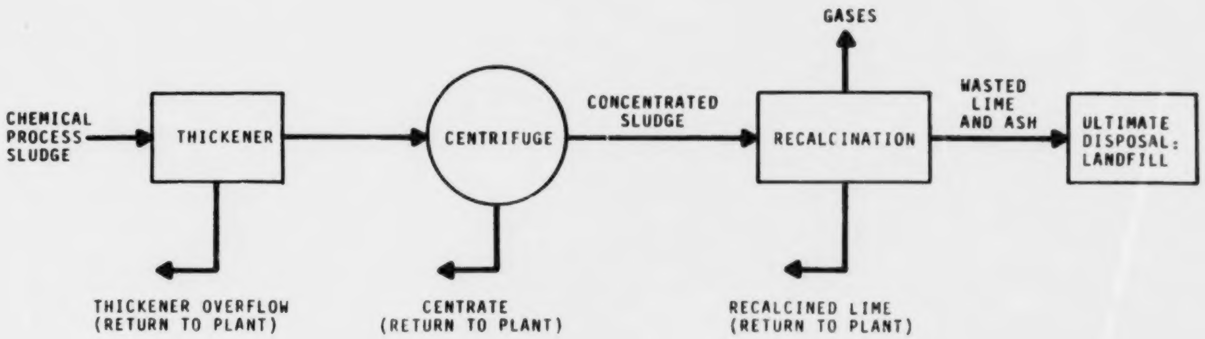
CHEMICAL PROCESS SLUDGE
THICKENER
CENTRIFUGE
CONCENTRATED SLUDGE
RECALCINATION
GASES
WASTED LIME AND ASH
ULTIMATE DISPOSAL: LANDFILL
THICKENER OVERFLOW (RETURN TO PLANT)
CENTRATE (RETURN TO PLANT)
RECALCINED LIME (RETURN TO PLANT)

FIGURE 21. SLUDGE OPTION 12: CHEMICAL SLUDGE THICKENING, CENTRIFUGE DEWATERING, RECALCINATION AND REUSE, AND LANDFILL OF WASTED RESIDUE

SUMMARY

Three environments are potentially affected by operation of a wastewater treatment plant:

- Air
- Land, and
- Water.

Potentially, the ultimate sink of all discharges from wastewater treatment plants (as well as other sources) is the ocean. Unfortunately, relatively little is known or understood concerning the ultimate capacity of the ocean to accept wastes, its rate of cleansing the numerous types of wastes, the physical and biological effects of waste products, and the relation between mankind's existence and the ocean's purity. A lack of understanding should not result in the indiscriminate disposal of wastes into the ocean simply because detrimental effects have yet to be proven. Rather, the approach should be geared toward ocean disposal of only wastes known to cause little, if any, significant degradation. Similarly, caution must be taken to protect the intermediate sinks.

The three intermediate sinks: air, land, and surface water (excluding oceans) are affected by effluent disposal in varying degrees. The emission of airborne particulate matter and gases to the atmosphere from treatment plants is normally confined to such operations as biological treatment facilities, digestion, incineration, and a few physical-chemical treatment schemes (e.g., ammonia stripping). The majority of the gaseous products from the biochemical reactions occurring within a treatment plant are carbon dioxide, methane and nitrogen. In most cases, the major sources of methane can be contained and the gas utilized for various purposes within the plant. The other gases are natural to the atmosphere. On the other hand, the main source of particulate emissions is the sludge incineration process. The inclusion of properly designed wet scrubbers, cyclones, or electrostatic precipitators can minimize the quantity of emissions actually reaching the atmosphere. That quantity which manages to reach the atmosphere from treatment processes will eventually be deposited upon the land, in surface water, or in the ocean. In general, such quantities of material are minimal and have little impact upon the environment.

Presently, the quantity of wastewater treatment plant effluent reaching the surface water in the United States is significant. The composition of these effluents varies immensely from one site to another. Depending upon the assimilative capacity of the surface water, the effluent characteristics, and the relative quantities involved, surface water disposal of treated effluent may or may not be an appropriate alternative. Such disposal will normally eliminate the utilization of valuable nutrients in the effluent for crop production or land reclamation. On the credit side, it will help recharge valuable water supplies.

Land disposal of liquid and solid effluents has been receiving increasing attention. The cleansing capabilities of soils and the potential for nutrient utilization for crop production makes land spreading quite appealing. However, here again, the amount of knowledge available concerning the ultimate effect of massive land spreading ventures is limited. The decay of pathogenic organisms and the saturation of the soils with heavy metals are two unanswered potential problems associated with the long-term land spreading of waste treatment plant effluents. Furthermore, the residence time of most constituents of any wastewater effluent will probably be much longer in the soil than in a stream or river.

Each potential treatment plant site must be evaluated on a case-by-case basis. The final disposal site will also influence the operating and maintenance and capital costs, as well as many other parameters as outlined below.

The graphical summaries presented in the following pages characterize many of the input and output parameters associated with the liquid treatment and sludge handling options analyzed within this report. These graphs indicate various prominent trends in the data presented on the process profile sheets and illustrate some of the comparisons which should be made in order to properly analyze and compare the wastewater treatment alternatives available. The danger inherent in the presentation of the data in this manner is that the trends illustrated in the figures are only representative of the data developed under the unit process and unit operation assumptions of this text, and of the assumed domestic wastewater quality characteristics. Hence, the trends taken out of context may not represent any particular wastewater treatment plant site. The reader should utilize these figures prudently and should refer to the profile and computational sheets in order to develop applicable rough estimates of treatment alternatives for a particular location.

When reviewing the figures, the reader must be careful to compare treatment strategies at similar flow rates since comparisons of strategies at different flow rates will result in erroneous conclusions. Moreover, these comparisons, while being useful for providing a quick insight into the relative inputs and outputs of each treatment system, must be viewed in the light of the type of system applicable for each proposed treatment site. The geographical location of a site may cause the elimination of some of the alternatives evaluated in this text as would the quantity of wastewater to be treated.

The figures presented have all been normalized in order to provide the reader with a visual comparison of the various treatment strategies presented within the text of this report. Hence data is given per unit volume of water or per unit quantity of sludge.

Figure 22 graphically illustrates the following liquid treatment input parameters: 1) labor requirements (Figure 22-A); 2) energy consumption (Figure 22-B); 3) operating and maintenance costs (Figure 22-C); 4) capital costs (Figure 22-D); and 5) land requirements (Figure 22-E). Figure 22-A also contains a code indicating the level of operator skill which must be maintained in order to provide efficient plant operation. The low, medium, and high ratings have been developed on a comparative basis between the various types of treatment plants evaluated. A rating of "high" would indicate the necessity for employing skilled and well trained operators.

Figure 23 graphically illustrates the same input parameters presented in Figure 22 for sludge treatment and disposal. As previously stated, all comparisons are contingent upon the assumptions presented in this report. Absolute quantitative data can be obtained for each individual process from the specific profile sheet. In reviewing these graphs, Figures 22 and 23, and the two following sets of graphs, Figures 24 and 25, it should be recalled that the strategy and option numbers refer to treatment systems as outlined below:

Liquid Treatment Strategy #1 - Primary Treatment with Land Application
2 - Waste Stabilization Lagoon
3 - Trickling Filter with Surface Water Discharge
4 - Trickling Filter with Land Application
5 - Activated Sludge with Surface Water Discharge
6 - Activated Sludge with Land Application
7 - Biological-Chemical Treatment
8 - Activated Sludge - Coagulation - Filtration
9 - Tertiary Treatment
10 - Physical-Chemical Treatment
11 - Extended Aeration

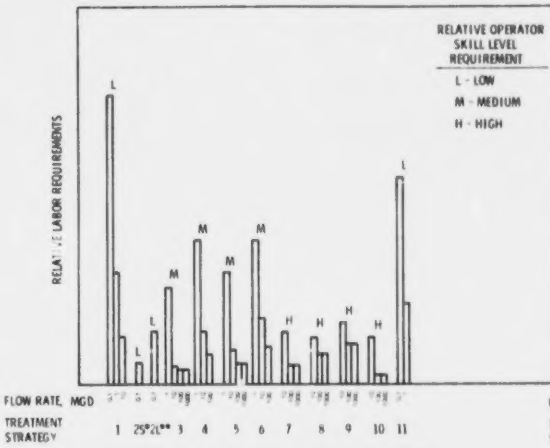

FIGURE 22-A: RELATIVE LABOR REQUIREMENTS PER UNIT CAPACITY

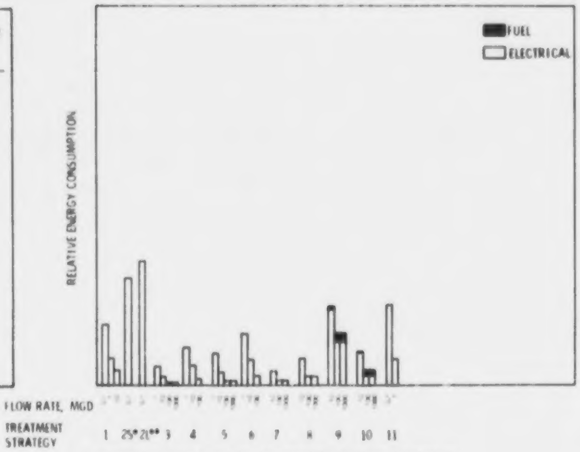

FIGURE 22-B: RELATIVE ENERGY CONSUMPTION PER UNIT CAPACITY

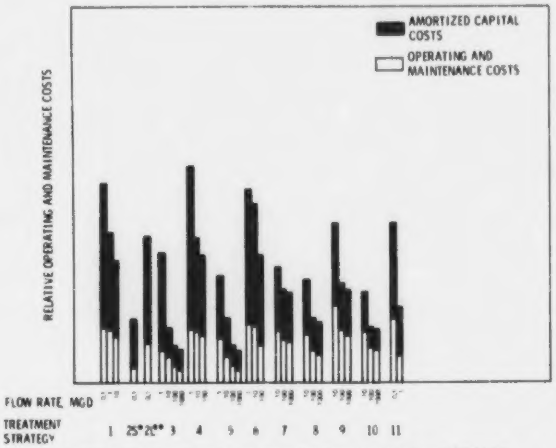

FIGURE 22-C: RELATIVE OPERATING AND MAINTENANCE COSTS PER UNIT CAPACITY

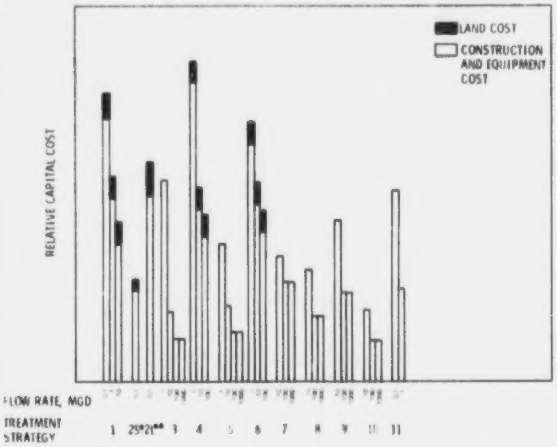

FIGURE 22-D: RELATIVE CAPITAL COSTS PER UNIT CAPACITY

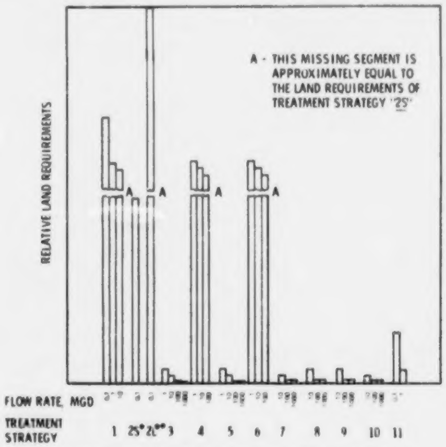

FIGURE 22-E: RELATIVE LAND REQUIREMENTS PER UNIT CAPACITY

*S=Surface water disposal of liquid effluent
**L=Land disposal of liquid effluent

FIGURE 22. INPUT CHARACTERIZATION FOR LIQUID TREATMENT STRATEGIES

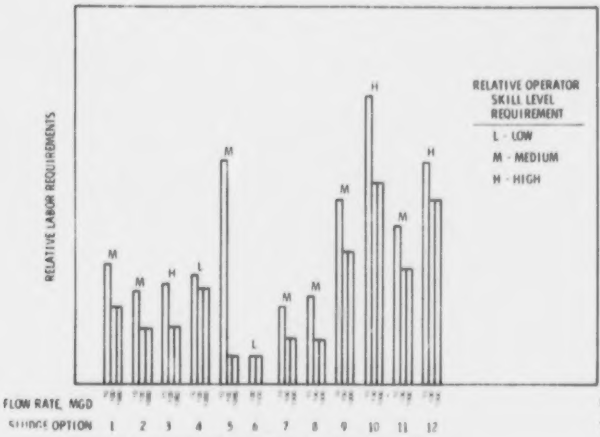

FIGURE 23-A: RELATIVE LABOR REQUIREMENTS PER UNIT CAPACITY

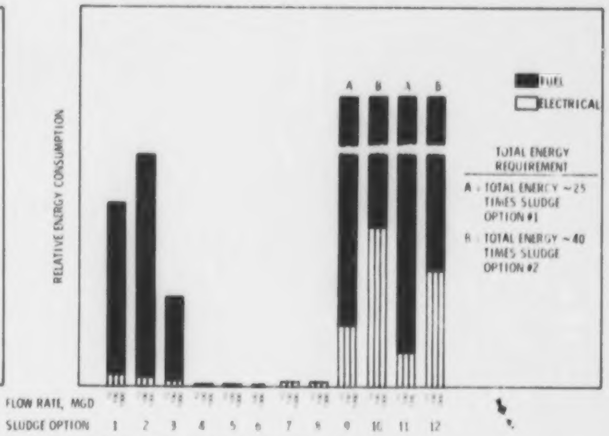

FIGURE 23-B: RELATIVE ENERGY CONSUMPTION PER UNIT CAPACITY

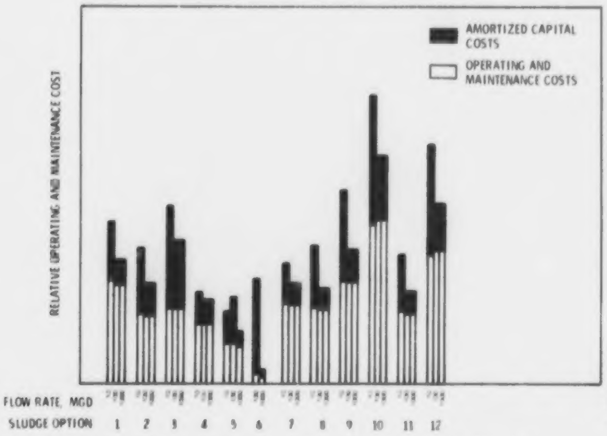

FIGURE 23-C: RELATIVE OPERATING AND MAINTENANCE COSTS PER UNIT CAPACITY

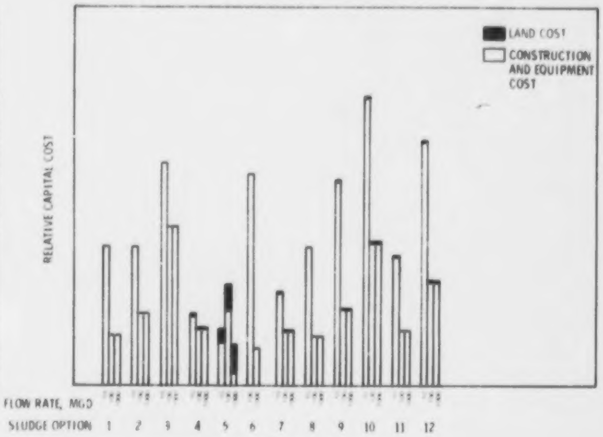

FIGURE 23-D: RELATIVE CAPITAL COSTS PER UNIT CAPACITY

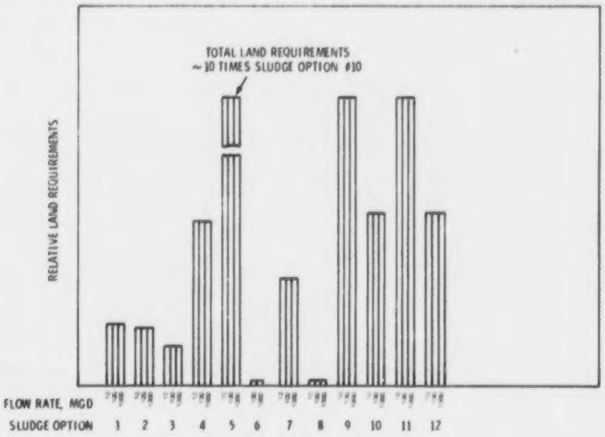

FIGURE 23-E: RELATIVE LAND REQUIREMENTS PER UNIT CAPACITY

FIGURE 23. INPUT CHARACTERIZATION FOR SLUDGE TREATMENT AND DISPOSAL ASSUMING INFLUENT SLUDGE FROM LIQUID TREATMENT STRATEGY #8

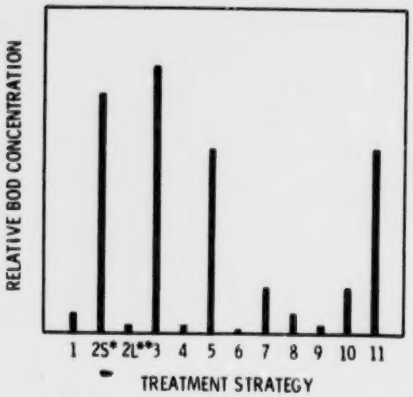

FIGURE 24-A: RELATIVE BOD EFFLUENT CONCENTRATIONS

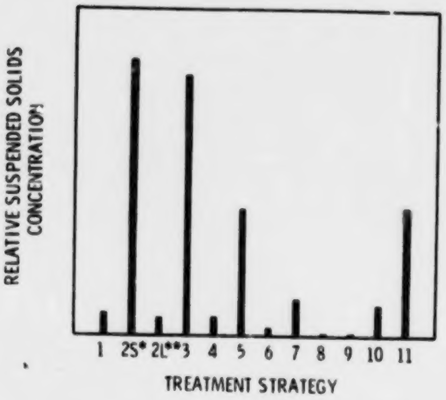

FIGURE 24-B: RELATIVE SUSPENDED SOLIDS EFFLUENT CONCENTRATIONS

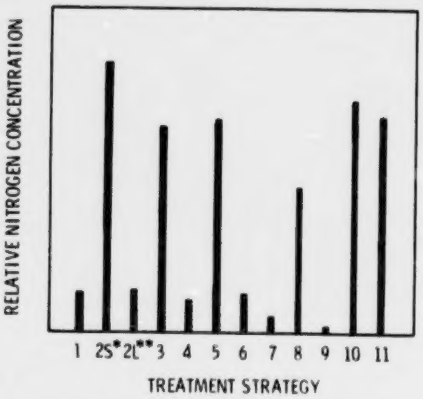

FIGURE 24-C: RELATIVE NITROGEN EFFLUENT CONCENTRATIONS

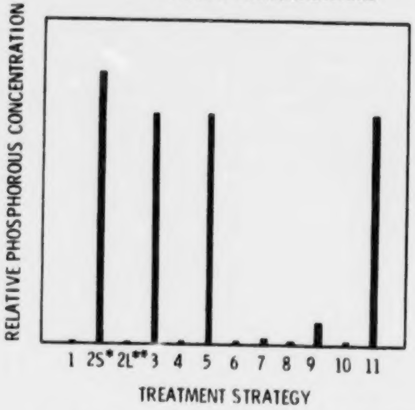

FIGURE 24-D: RELATIVE PHOSPHOROUS EFFLUENT CONCENTRATIONS

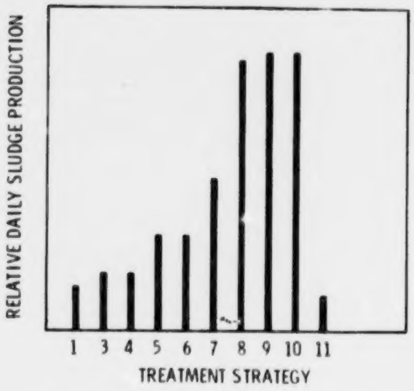

FIGURE 24-E: RELATIVE SLUDGE PRODUCTION PER UNIT CAPACITY

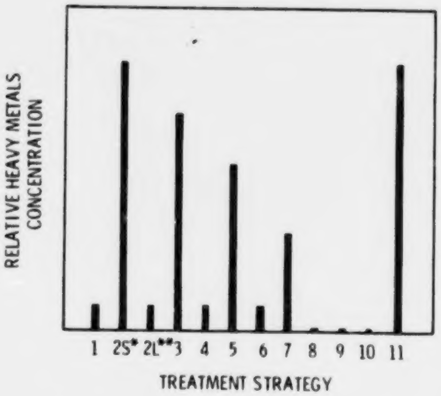

FIGURE 24-F: RELATIVE HEAVY METALS EFFLUENT CONCENTRATIONS

**S=Surface water disposal of liquid effluent*
***L=Land disposal of liquid effluent*

FIGURE 24. OUTPUT CHARACTERIZATION FOR LIQUID TREATMENT STRATEGIES

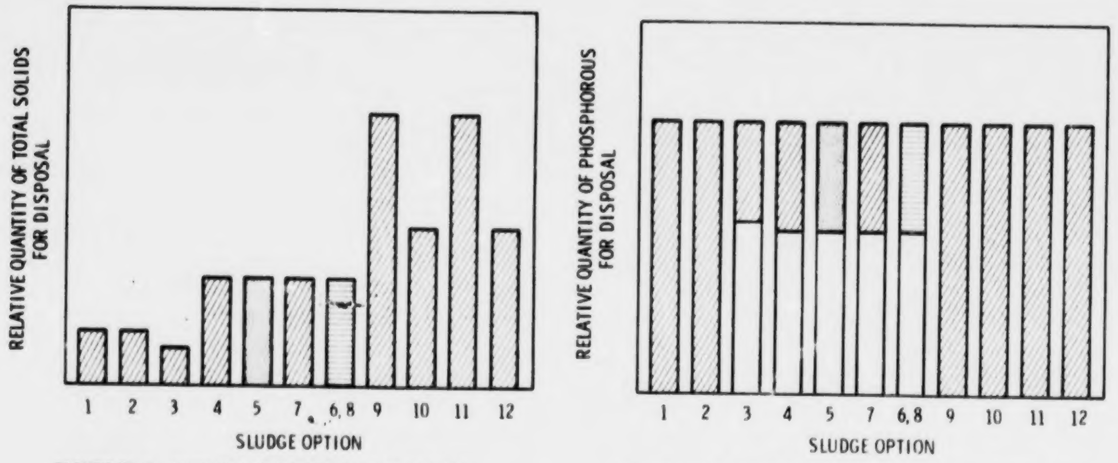

FIGURE 25-A: FATE OF SOLIDS FOR SLUDGE DISPOSAL OPTIONS

FIGURE 25-B: FATE OF PHOSPHOROUS CONTENT FOR SLUDGE DISPOSAL OPTIONS

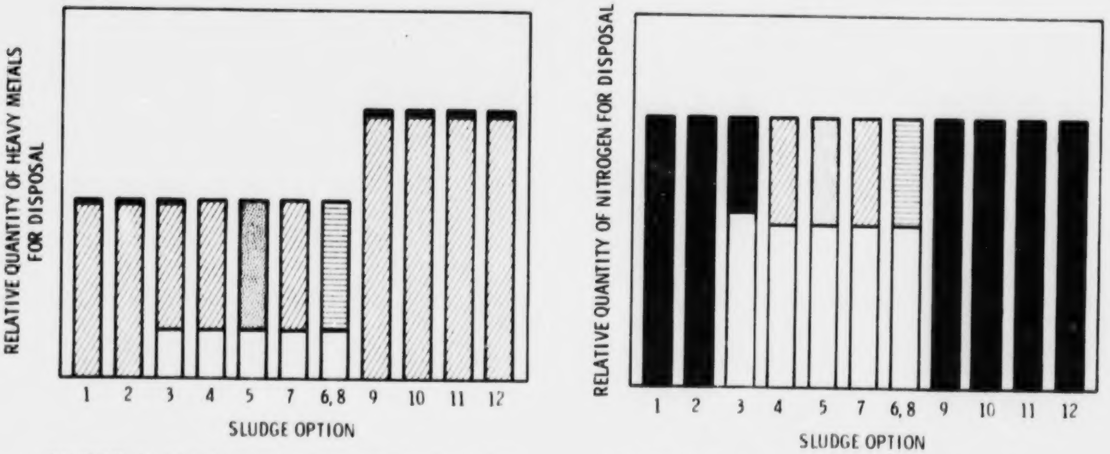

FIGURE 25-C: FATE OF HEAVY METALS CONTENT FOR SLUDGE DISPOSAL OPTIONS

FIGURE 25-D: FATE OF NITROGEN CONTENT FOR SLUDGE DISPOSAL OPTIONS

OUTPUT
DISPLACEMENT LEGEND

- ■ AIR
- ▨ LANDFILL
- ▒ LAND SPREADING
- ☐ OCEAN
- ☐ RETURN TO TREATMENT PLANT

FIGURE 25. OUTPUT CHARACTERIZATION PER UNIT CAPACITY FOR SLUDGE TREATMENT AND DISPOSAL ASSUMING INFLUENT SLUDGE FROM LIQUID TREATMENT STRATEGY #8

Sludge Treatment
and Disposal Option #1 - Thickening - Conditioning - Filtration - Incineration - Landfill
2 - Conditioning - Centrifugation - Incineration - Landfill
3 - Thickening - Heat Treatment - Filtration - Incineration - Landfill
4 - Thickening - Digestion - Sod Drying - Landfill
5 - Thickening - Digestion - Land Spreading
6 - Thickening - Digestion - Ocean Disposal
7 - Thickening - Digestion - Conditioning - Filtration - Landfill
8 - Thickening - Digestion - Conditioning - Filtration - Ocean Dumping
9 - Chemical Sludge Thickening - Filtration - Incineration - Landfill
10 - Chemical Sludge Thickening - Filtration - Recalcination
11 - Chemical Sludge Thickening - Centrifugation - Incineration - Landfill
12 - Chemical Sludge Thickening - Centrifugation - Recalcination

All sludge input numbers were derived based on sludge produced from an activated sludge plant followed by coagulation and filtration (Liquid Treatment Strategy #8). This strategy was selected because it generates both biological and chemical sludges. It was also selected on the basis of widespread use of activated sludge systems throughout the United States.

Figure 24 graphically illustrates the following liquid treatment output parameters: 1) BOD (Figure 24-A); 2) suspended solids (Figure 24-B); 3) nitrogen (Figure 24-C); 4) phosphorous (Figure 24-D); 5) sludge production (Figure 24-E); and 6) heavy metals (Figure 24-F). The effluent concentration figures reflect the relative concentration of a specific parameter reaching the final sink. For purposes of this study, the final liquid disposal sink has been defined as either surface water or groundwater. Strategies 2S, 3, 5, and 7-11 discharge to surface water while the remaining strategies dispose the liquid effluent on land. It is assumed that in these cases of land application, the effluent eventually reaches groundwater.

Figure 25 graphically illustrates the same output parameters presented in Figure 24 for sludge treatment and disposal options. The relative figures indicate the percentage of the output from the treatment plant which is distributed to the air, land, or ocean. Those outputs which are recycled to the plant represent the contaminants left in the liquid fraction which will be returned for liquid treatment processing. Their ultimate fate will be determined by the disposition of the liquid effluent.

Figure 26 illustrates the fractional distribution of the total operating costs per unit capacity for both the liquid treatment strategies and the sludge treatment and disposal options.

Table I represents a qualitative analysis of several parameters affecting the level of performance of a treatment plant. This table is provided as a guide to the reader in understanding the complexities involved in various treatment strategies as well as the potential dangers of improper plant operation. Sensitivity to Fluctuations (refer to Table I) measures the ability of the plant to continue to maintain its design performance in the wake of changing wastewater characteristics, climatic fluctuations and other alterations. In this case, a low rating would indicate that the plant's efficiency is not significantly influenced by such fluctuations whereas a high rating would indicate that the treatment strategy's efficiency is significantly altered by changing environmental factors.

Necessary Level of Operator Attentiveness is a measure of the system's demand upon the operator's awareness. A low rating indicates that the system does not require constant operator attention.

Magnitude of Failure Due to Operator Inattentiveness is a measure of the potential consequences should operator inattention sponsor plant failure. A low rating would indicate that plant failure would result in an insignificant decrease in treatment levels and hence would not lead to excessive environmental degradation or health hazards. The strategies with these ratings typically include redundant unit operations. A high rating would reflect a potential significant increase in the level of contaminants in the effluent water and therefore a concomittant increase in environmental degradation and health hazard should the plant fail to operate efficiently as a result of operator inattention. Strategies with these ratings typically include sensitive unit operations and little overlapping treatment capability.

Table II is a tabular display of a similar qualitative analysis of the sludge handling options as was illustrated in Table I for the liquid treatment strategies. In this case, Sensitivity to Fluctuations and Necessary Level of Operator Attentiveness hold the same meanings as previously discussed for the liquid treatment strategies. Failure of these sludge handling schemes is not viewed as a health hazard or an immediate threat to the environment. In general, such a failure will temporarily require the plant to handle and dispose of the sludge in a less optimal manner.

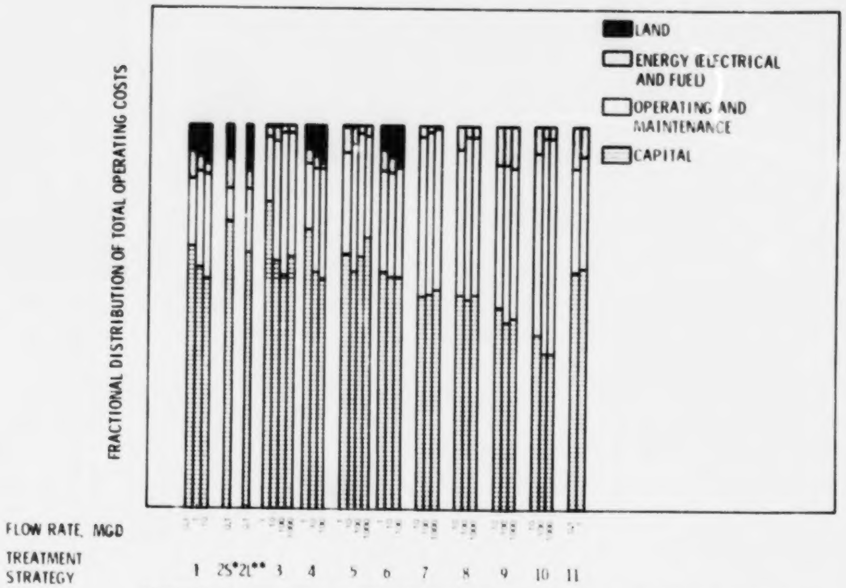

FIGURE 26-A: FRACTIONAL DISTRIBUTION OF TOTAL OPERATINGS COSTS PER UNIT CAPACITY FOR LIQUID TREATMENT STRATEGIES

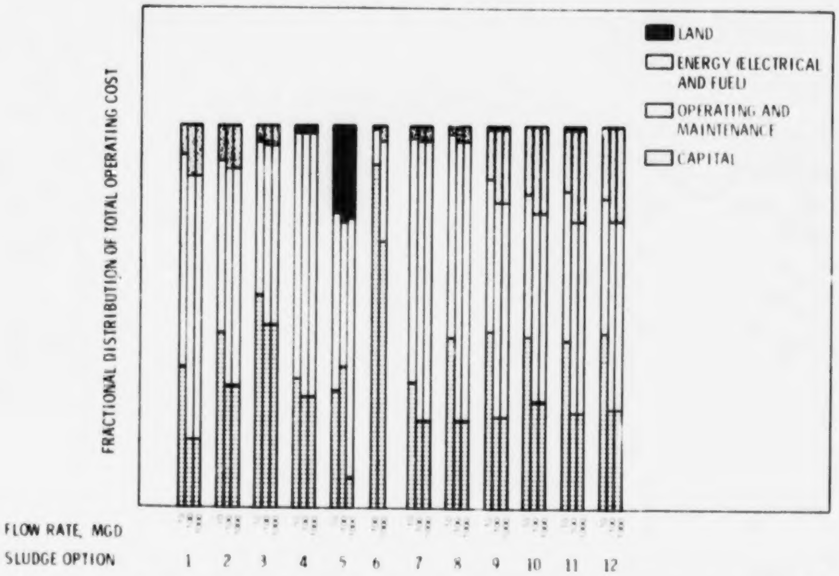

FIGURE 26-B: FRACTIONAL DISTRIBUTION OF TOTAL OPERATING COSTS PER UNIT CAPACITY FOR SLUDGE TREATMENT AND DISPOSAL
(ASSUMES INFLUENT SLUDGE FROM LIQUID TREATMENT STRATEGY #8)

*S=Surface water disposal of liquid effluent
**L=Land disposal of liquid effluent

FIGURE 26. TOTAL OPERATING COST STRUCTURE FOR LIQUID AND SLUDGE TREATMENT AND DISPOSAL ALTERNATIVES

TABLE I

ANALYSIS OF PARAMETERS AFFECTING LIQUID TREATMENT STRATEGY PERFORMANCE

	Treatment Strategy											
Parameter	1	2S	2L	3	4	5	6	7	8	9	10	11
Sensitivity to Fluctuations	Low	Med	Med	Med	Med	Med	Med	High	Med	Low	Low	Med
Necessary Level of Operator Attentiveness	Low	Low	Low	Med	Med	Med	Med	High	Med	High	High	Low
Magnitude of Failure Due to Operator Inattentiveness	Low	Med	Low	Med	Low	High	Med	High	Med	High	High	Low

TABLE II

ANALYSIS OF PARAMETERS AFFECTING SLUDGE HANDLING OPTION PERFORMANCE

	Treatment Strategy											
Parameter	1	2	3	4	5	6	7	8	9	10	11	12
Sensitivity to Fluctuations	Low	Low	Low	High	Med	Med	Med	Med	Med	Med	Med	Med
Necessary Level of Operator Attentiveness	Med	Med	High	Low	Med	Low	Med	Med	Med	High	Med	High

The figures and tables, along with the profile sheets, lead to the following general conclusions.

- No single liquid treatment strategy or sludge disposal option is optimal for all situations. Rather, there are a number of acceptable alternatives with inherent advantages and disadvantages which change in relative importance as a function of site-specific variables. Consequently, regulatory policy and guidelines must permit flexibility in the decision making process.

- All liquid treatment strategies evaluated are capable of meeting existing discharge regulations if properly designed and operated. Selection between individual strategies will depend on prevailing conditions at the proposed site.

- Although land application was the only liquid treatment practice evaluated for the removal of nutrients from small volume wastewater flows, increased consideration should be given to the addition of chemicals to primary and secondary treatment facilities for small plants in areas where land application is not possible.

- Land application of effluents can be an economical alternative for achieving high levels of organic and nutrient removal. Additional research is needed, however, before the application of treatment plant effluent to food and feed grain crops should be encouraged on a widespread scale.

- All sludge disposal options evaluated were found to be acceptable if properly designed and operated. Selection of individual courses of action will depend greatly on the conditions prevailing at the proposed site.

- Land spreading of organic sludges offers the potential for both disposal of a waste material, and resource recovery of nutrient materials otherwise wasted. Because experience is limited, unanswered questions still exist concerning the public health effects and length of soil exhaustion cycle associated with this practice

- Land spreading of sludges should receive special attention in areas where strip mining activities have been intensive since the organic content and available nutrients can have a beneficial impact on the otherwise relatively sterile soil.

- Incineration is one of the best developed methods for disposal of sludges, but it affords little opportunity for the reclamation of resources, and it places heavy energy demands on the community. More work is needed to identify specific stack gas contaminants and establish emission standards for individual toxicants.
- Ocean disposal represents one of the least expensive methods available both in terms of economic costs and resource utilization. More research is needed, however, to gain a better understanding of potential degrading effects.
- Sanitary landfills are an especially attractive alternative for municipalities currently disposing of solid wastes in a similar manner.
- Advanced waste treatment schemes are typically energy intensive and thus may be increasingly difficult to institute. Work is needed to develop new alternatives with lower energy demands.
- Additional work is required to detail the secondary effects associated with various treatment options. This will allow for optimization from a system overview.
- Grant and bonding provisions in the present laws favor selection of capital intensive alternatives. In many cases, these alternatives may not be the best technical choices, the least cost choices, nor will they necessarily result in the least burden being placed on the environment.
- Grant and bonding provisions also discriminate against development of private utilities for the treatment of municipal wastes. Such utilities could be beneficial in sponsoring economical regionalization of facilities and continued innovation in waste treatment.

LIQUID TREATMENT STRATEGIES AND SLUDGE DISPOSAL OPTIONS

GENERAL

A community faces a monumental task when it must consider constructing new, or improving existing wastewater treatment facilities. There is no single treatment system which is best for all particular situations. All treatment alternatives considered in this study could achieve the presently required degree of treatment if properly designed, constructed, and operated.

The technical and cost information presented in this report can be used as a guideline in selecting various alternatives from a technical standpoint. However, there are several non-quantitative considerations that are also pertinent. First, the competence of the consulting engineer who is responsible for the design and administration of construction activities of the treatment facility must be considered. Consulting engineers throughout the U.S. generally are conservative in nature and tend to bias the selection of treatment options towards traditional, well established systems. Many firms are not familiar with the more recent innovations in waste treatment technology and are unwilling and/or unable to give advanced systems adequate consideration. Therefore, in selecting an architect-engineering firm, it is extremely important to consider the past experience and capability of the consulting engineer to cope with the increasing complexities involved in the selection and design of modern wastewater management systems. Many municipalities tend to engage local firms or firms with which they have traditionally dealt for general engineering assistance. Such practice does not necessarily result in selection and implementation of the optimum wastewater treatment strategy.

Operating personnel at a wastewater treatment facility are a major factor in the success or failure of the facility to perform according to facility design expectations. Considerable experience and training are required of operating personnel to assure that a treatment facility will consistently achieve high levels of treatment. Many communities have the attitude that treatment plants essentially run themselves. All treatment facilities must be operated with full knowledge of the process and constant monitoring of the effluent. Improper management of any facility can result in a failure to meet treatment requirements. Historically, failure of many treatment facilities to perform up to design expectations has been the result of poor operational practices.

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Several general assumptions are implicit in the data presented in this report. It is assumed that infiltration is minimized and thus daily flows average 100 gpcd. Plants are operated on a 24 hour per day, 365 day per year basis with average efficiency unless otherwise noted. When older cost data was all that could be found, figures were updated to 1973 costs using a five percent inflation factor.

Domestic sewage is characterized in Table III. In all cases, medium strength sewage was assumed in this work. It is recognized that larger municipalities often handle a greater volume of industrial wastes than smaller ones and hence may be better characterized by the high strength sewage detailed in Table III. The generalization, however, is not an easy one to make since the degree of variation in wastewater strength will depend both on the type of industry and the manner in which specific plants are operated. Rather than attempt to differentiate the quality of wastes for larger flows, and thus accept the above generalization, the medium strength sewage assumption was made. This puts all comparisons between unit inputs and outputs on an equivalent base.

When wastes are found to be stronger than those assumed in this study, some corrections in sizing and evaluating treatment facilities will be in order. Many biological processes are limited by organic loading rather than hydraulic loading. For these processes, stronger wastewaters clearly require larger facilities. Waste strength may also approach a point where plant effluent recycle or other means of dilution are required to effect better treatment. Thus, when stronger wastes are anticipated, caution must be taken in reviewing the data presented herein.

The one generalization that can be made about wastes received by plants with industrial contributors relates to their higher heavy metals content. These materials as well as other waste constituents can affect process design and selection because of their chemical and toxicological properties. This situation, however, is in a state of flux. Section 307 of the Federal Water Pollution Control Act Amendments of 1972 requires the formulation of pretreatment standards for all industrial wastes routed to municipal sewers. These regulations will tend to reduce heavy metal inputs in sewage to levels closer to those assumed in the present study. Pretreatment standards, however, will not eliminate differences in pollutant levels since they are not addressed to nonpoint sources. Hence, municipalities served by combined storm-sanitary sewer systems may continue to receive high levels of some metals and compounds such as commercial pesticides.

TABLE III

TYPICAL CHARACTERISTICS OF DOMESTIC
SEWAGE IN THE UNITED STATES[6,31]

Constituents	Weak	Medium	Strong
Physical Characteristics			
Color (nonseptic)	Gray	Gray	Gray
Color (septic)	Gray-Black	Blackish	Blackish
Odor (nonseptic)	Musty	Musty	Musty
Odor (septic)	Musty-H_2S	H_2S	H_2S
Temperature-°F (average)	55°-90°	55°-90°	55°-90°
Total solids* (mg/l)	450	800	1200
Total volatile solids (mg/l)	250	425	800
Suspended solids (mg/l)	100	200	375
Volatile suspended solids (mg/l)	75	130	200
Settleable solids-$\frac{(ML)}{L}$	2	5	7
Chemical Characteristics			
pH (units)	6.5	7.5	8.0
Cl, SO_4, Ca, Mg, etc.*	15	40	60
Total nitrogen (mg/l)	5	14.5	19
Organic nitrogen (mg/l)	10	25	40
Ammonia nitrogen (mg/l)	-	0.5	1.0
Nitrate nitrogen (mg/l)	5	15	30
Total phosphate-PO_4 (mg/l)			
Biological Characteristics			
Total bacteria $\left(\frac{\text{counts}}{\text{100 ml}}\right)$	1×10^8	30×10^8	100×10^8
Total coliform $\left(\frac{\text{MPN}}{\text{100 ml}}\right)$	1×10^6	30×10^6	100×10^6
Biochemical oxygen demand	100	200	450

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*Quite variable depending on natural water quality of region.

The complexity of these and other factors related to determining the strength of sewage underscores the necessity for adequate analysis of all wastewaters prior to process selection. Design decisions can only be made on a site specific basis.

All operations are assumed to be accomplished within the existing regulatory requirements. Consequently, effluent standards for air and water, pretreatment requirements for toxic substances, and specific operating guidelines for such practices as ocean dumping and incineration are anticipated in the data. The effect of such assumptions is largely seen in the capital and operating costs where additional equipment and higher input requirements are necessitated.

Operating performance data has been taken largely from empirical data averages and thus represents what can be expected under typical or normal range environmental conditions. Extremes in temperature, flow variation, or other parameters will have adverse effects on actual plant performance. The impact of changes in significant parameters on specific treatment alternatives is addressed in the sensitivity discussion included with each process description.

Selection of alternatives can be best approached in a stepwise fashion. First all viable options are selected for the required flow rate. Then comprehensive comparisons of costs, resource needs, and outputs are made for candidate processes. This step is somewhat of an iterative one due to the interrelations between liquid treatment and sludge production. When acceptable candidates have been ranked in order of desirability, environmental extremes specific to the site under consideration must be identified. Review of the impact of changes in these parameters from the norms assumed in the general profile development will then lead to refinement of alternative rankings more reflective of the actual site under consideration. The final ranking should then represent the optimal treatment strategy for a given site. The selection, however, will have been made on a comparative basis. Data from the profile sheets should not be considered as accurate design estimates for any given plant.

LIQUID TREATMENT STRATEGIES

Numerous wastewater treatment alternatives are available to treat municipal wastewater. Those alternatives selected for analysis in this study are by no means exhaustive of the methods available. However, the eleven strategies in this study are representative of various alternatives which will provide efficient, reliable wastewater treatment in compliance with present regulations.

Primary Treatment with Land Disposal of Effluent

Primary treatment followed by land disposal of effluents corresponds with Strategy #1. This alternative, which is fully described in Appendix A of this report, is especially attractive in regions with large areas of uncommitted land available for use as a wastewater spray field. The soil characteristics and land availability are key considerations in the selection of this alternative. For this strategy, approximately 129 acres of land are required for a population equivalent of 10,000. More land would be required in regions with clay type soils. This alternative is most attractive for areas in the midwest, west and southwest regions of the United States. It is especially desirable in locations where irrigated agriculture is presently in use.

Variations in land values and availability are particularly important in comparing this practice with other alternatives. In some respects, use of land for treatment can be construed as an investment for the city since land values are more likely to rise than fall. Gain on the resale of the land when its capacity as a disposal site is exhausted may well be offset by increased prices of the replacement disposal option.

The nutrients in wastewater and the water itself may be considered as a resource. The growing and harvesting of crops for animal feed may offset some of the operating expenses incurred. However, different state health agencies have differing policies regarding crops which may or may not be irrigated with wastewater treatment effluents and, therefore, these agencies must be consulted. Aerosols containing bacteria and virus may result from spray irrigation of wastewater and may be transported by winds for some distance. Thus, buffer strips are generally required around the spray sites as a health protective measure. Also spray irrigation sites should be fenced so as to restrict the movement of people through the spray area.

Regions which experience prolonged cold temperatures must provide for storage of effluent. Since spraying on frozen ground is generally not acceptable, storage basins must be sized to store wastewater effluent produced during the period of freezing plus effluent that must be stored when precipitation causes the curtailment of spray disposal operations. Thus, it can be seen that land requirements may be considerably greater in the colder northern regions.

Waste Stabilization Lagoon

The purification of wastewaters from small communities, small industrial works, dairies, and canneries presents a significant problem because of the costs of constructing and operating a small waste treatment plant. Waste stabilization ponds (Strategy #2 described in Appendix A of this report) were developed as a simplified low cost method of treating such wastes. No preliminary treatment is required and the system is of the simplest construction, usually an earthen basin.

Stabilization ponds, with discharge of effluent to surface waters, may be constructed in a series arrangement to achieve high levels of BOD and pathogen removal. A combination of anaerobic and aerobic ponds can achieve levels of treatment equal to that of other secondary biological alternatives.

Stabilization ponds may be constructed on a non-overflow basis, relying on evaporation for disposal of liquid. However, the land requirement for this type of system generally becomes prohibitive because the evaporation rate is dependent on surface area. For a non-overflow system, evaporation rate must equal wastewater flow rate.

Stabilization ponds with effluent discharged to the land via spray irrigation are essentially solids removal and holding basins.

The major consideration for land disposal of effluents from stabilization ponds would be nutrient removal. Stabilization ponds provide little or no nutrient removal. Therefore, communities with a nutrient removal requirement pursuant to discharge to surface waters may need to consider land treatment. However, the total land requirement will significantly increase.

This strategy alternative may produce offensive odors if not operated and maintained properly. Anaerobic conditions cause the evolution of extremely odorous gases.

Waste stabilization pond profiles were constructed only for very small communities (less than 1 MGD flow).

Trickling Filter

Strategies #3 and #4, as described in Appendix A of this report, consist of trickling filter biological secondary treatment followed by discharge to surface waters (Strategy #3) or discharge to the land via spray irrigation (Strategy #4).

Trickling filtration became a popular method of biological treatment primarily due to the reliability of the process. Unfortunately, this dependability is accompanied by a reduced efficiency for removal of BOD. However, dependability is the basis for its continued use. Trickling filters are highly insensitive to fluctuations in influent flow and organic composition and achieve BOD removals of 85 percent almost independently of such hydraulic and organic fluctuations. The trickling filter process can effectively treat the large volumes of wastewater from large communities.

Discharge of trickling filter effluent to surface waters (Strategy #3) is an acceptable method of effluent disposal. However, assuring that trickling filter effluents consistently meet effluent standards necessitates continuous monitoring of the effluent and subsequent corrections for maintenance of treatment efficiency.

Improvements in trickling filter technology have been less dramatic than those associated with activated sludge systems. Major improvements have been made in the filter media, where the use of plastic and other materials have been utilized to allow for increases in hydraulic and organic loadings. A former objection to trickling filters was the large land area required. Now with newer media, they may be constructed in tower form, thus reducing the land requirement substantially.

Land disposal of secondary treatment effluents (Strategy #4) will not be universally acceptable, especially for larger communities. Coupled with the tendency for trickling filters to not consistently meet increasing removal requirements for discharge to surface waters without excessive operator control, trickling filters are not generally preferred to activated sludge units. Use, however, continues in many areas. Trickling filters continue to be the optimal treatment method for communities that receive large quantities of carbohydrate wastes. This would be the case for small municipalities which receive large portions of input from food processing plants or canneries.

Activated Sludge

Treatment strategies #5 and #6, described in Appendix A of this report, include the activated sludge process for secondary treatment. Strategy #5 utilizes surface water disposal of effluents and Strategy #6 utilizes land application of effluents.

Activated sludge systems are capable of providing good BOD removals (up to 90 percent). Conventional activated sludge systems are thought to be more easily upset than trickling filter systems, but this is not the case for the complete mix process. In fact, the complete mix activated sludge process meets the optimum conditions now known to be necessary for a stable, predictable biological system.

Communities that incorporate large industrial developments for wastewater treatment should consider the complete mix activated sludge process. It is especially adaptable to the large fluctuations in flow and organic loadings caused by most industries. However, wastes containing high carbohydrate concentrations can cause a "bulking" sludge, which generally results in operational problems and attendant loss in effluent quality. Such wastes, characteristic of food processing operations, are better handled with trickling filters.

This system is quite compatible with other (physical-chemical) processes as required for nutrient removal.

Considerations for disposal to land and surface waters have been noted previously.

Biological-Chemical Treatment

This approach, designated as Strategy #7 and described in Appendix A of this report, is designed to remove phosphorus and nitrogen from the wastewater effluent. The complete scheme includes primary treatment, activated sludge secondary treatment with alum coagulation, nitrification-denitrification, chlorination, and surface water discharge.

Presumably, in the next decade, regulations restricting total phosphorus and nitrogen concentrations in the effluent will be formulated, acted upon, and enforced. This aforementioned action will necessitate large communities (greater than 10 MGD flows) to consider the application of a biological or physical-chemical method of removing these nutrients.

Biological-chemical plants for small communities (less than 10 MGD) with relatively low quantities of nutrients in their wastewaters were not reviewed for construction of profile sheets.

Strategy #7 represents a biological and chemical precipitation method of lowering the overall quantity of total phosphorus and nitrogen reaching the surface waters. Alum precipitation of phosphorus diminishes the potential for eutrophication of surface waters, whereas nitrification-denitrification is employed to remove nitrogen from the waste stream and subsequently prevent potential high oxygen demands in the surface waters as well as eutrophication.

A biologically intensive method, such as this strategy, will necessitate a high level of operator training and skill in order to maintain relatively trouble-free operation, and is not presently amenable to the higher degree of automation which can be implemented in the physical-chemical treatment strategies.

Operationally, Strategy #7 will tend to be more susceptible to environmental upsets (e.g., temperature changes and shock loading) than would physical-chemical treatment plants. Strategy #7 is attractive for upgrading an existing plant which already has activated sludge secondary treatment and trained operators. In doing so, the plant managers must plan for potential plant upsets which will lower the overall annual plant efficiency.

One disadvantage of this treatment strategy for communities located in largely urban areas is its relative dependency on land compared to that of physical-chemical methods. Cost for purchasing the land required by the system could be exorbitant near the urban center itself. In these cases, land farther from the city must be employed and hence higher transportation costs incurred.

This strategy generates extremely large quantities of sludge which are typically difficult to dewater.

Activated Sludge-Coagulation-Filtration

Strategy #8, as described in Appendix A of this report, consists of primary treatment, complete mix activated sludge, lime coagulation, two-stage recarbonation, multi-media filtration, chlorination, and ultimate disposal to surface waters.

Profiles for this strategy were constructed for treatment facilities in the size range of 10 to 100 MGD. The process is especially applicable in areas where regulatory requirements restrict phosphorus concentration levels in effluents and where residual BOD and suspended solids represent a problem to existing activated sludge plants. Furthermore, since the tertiary process is basically a physical-chemical operation, the flexibility and adaptability of the modular component system allows the plant to be quite easily modified to meet increasingly stringent effluent requirements. Modular addition of carbon sorption and nitrogen removal facilities should be relatively simple.

Environmental factors such as climatic conditions, in general, have little effect upon the overall efficiency of the plant other than those inherent with the activated sludge process. Furthermore, due to the lower sensitivity to upset in this strategy, the overall average removal efficiency may be higher than with similar biological-chemical systems.

Tertiary Treatment

Strategy #9, as described in Appendix A of this report, consists of primary treatment, complete mix activated sludge, lime coagulation, two-stage recarbonation, filtration, carbon sorption, zeolite selective ion exchange, chlorination and ultimate disposal to surface waters.

This particular strategy, in contrast to Strategy #7, provides for physical-chemical removal of refractory organics, nitrogen and phosphorus to control oxygen demands and potential eutrophication. In general, the cost and land requirements for the preceding method of operation are equal to or higher than those for Strategy #7. The tertiary treatment provided by this scheme would be applicable to existing secondary activated sludge plants which now require additional organic and nutrient removal. A major advantage of this system is that it provides more positive control over the refractory organic and nutrient removal operations than does Strategy #7.

This strategy is sensitive to changes in pH. The pH from the two-stage recarbonation step must be near 7 in order to prepare the water for filtration, increase the efficiency of carbon sorption of organics, improve the disinfection by chlorination and provide a suitable pH for discharge into surface waters. In addition, the selective ion exchange process which removes ammonia from the wastewater stream is most effective at pH levels below 8.5.

Lime sludge production from this operation is quite large and recalcination can be a strong consideration in order to avoid dependence upon a chemical supplier and to conserve the use of natural resources. Furthermore, the cost savings from ash handling operations may economically justify recalcination.

In comparison to biological systems, the physical-chemical tertiary treatment proposed in this strategy is not as dependent upon environmental factors. The system is relatively insensitive to climate variations. Thus, it is preferred to Strategy #7 for areas with heavy industrial development or protracted periods of inclement weather. The reliance on activated sludge secondary treatment, however, preserves some sensitivity to variations in influent. Strategy #9 best serves as an alternative for upgrading existing activated sludge plants and will produce a higher quality effluent than any of the other strategies considered.

Profiles on Strategy #9 have been constructed for plants larger than 10 MGD.

Physical-Chemical Treatment

Strategy #10 is a complete physical-chemical treatment process, as described in Appendix A of this report. Lime addition in a rapid mix tank is followed by sedimentation in order to remove phosphorus. Two-stage recarbonation is then employed to lower the pH and recover excess $CaCO_3$. Suspended solids are removed in the filtration process, and dissolved organic species are removed in the carbon sorption step prior to chlorine disinfection and discharge to surface waters.

Profiles for this design were constructed for large treatment plant facilities (larger than 10 MGD). The process is quite applicable to regions where legislation restricting phosphorus concentrations in the effluent are binding.

The production of lime sludge is large and recalcination may be advisable in order to realize potential revenue benefits and conservation of natural resources. A tradeoff situation may exist related to the conservation of chemical and land resources as opposed to the higher energy requirements associated with recalcination versus incineration.

The relatively low land requirements of this option increase its attractiveness for urban areas where land values are high and availability is restricted.

In regions where nitrogen removal is also a concern, zeolite ion exchange could be added to this process for the removal of nitrogen. Hence, the scheme provides the advantage of flexibility and adaptability which is a key ingredient in order to meet increasingly stringent effluent requirements. This modular aspect of physical-chemical treatment is by far one of the major advantages which can be offered to a municipality. It is particularly attractive in areas expecting rapid growth, since it lends itself to staged construction and associated cost savings.

In general, the process is insensitive to environmental factors (e.g., climatic changes and shock loadings) and, therefore, average overall plant efficiencies of removal may be higher than biological systems. This feature makes Strategy #10 especially attractive to industrialized areas where strong or toxic wastes may occur. In general, the quality of the effluent produced by physical-chemical systems will be intermediate between secondary biological systems and tertiary systems.

Extended Aeration

Strategy #11, as described in Appendix A of this report, consists of the extended aeration process, which is a modification of the complete mix activated sludge process, and is utilized for small communities, industries, shopping centers, and schools.

Extended aeration minimizes sludge handling problems by operating with a long aeration period to aerobically oxidize waste sludge.

As a package plant, it is easily installed, but it must be operated and maintained efficiently like any other biological treatment system in order to perform satisfactorily. Frequently, these package plants are left unattended resulting in subsequent deterioration of effluent quality. For small communities that are required to meet increasingly stringent standards for wastewater treatment, extended aeration may be the system of choice. Waste stabilization (Strategy #2) is often preferred for its lower characteristic costs but is not capable of achieving the higher effluent qualities possible with extended aeration and may be far more objectionable to nearby residents.

SLUDGE DISPOSAL OPTIONS

Sludge Spreading

The spreading of organic sludge over soil is a viable ultimate disposal alternative. Land spreading offers the potential for resource recovery as well as being an acceptable disposal practice.

Sewage sludge does not compare favorably with commercial fertilizers when the comparison is based solely on nutrient content or ease of handling. Sewage sludge, however, does have exceptional soil conditioning characteristics which greatly enhance soil physical fertility. This property is best utilized in the reclamation of marginal lands for recreational, agricultural, or silvicultural purposes. Thus, land spreading of sludge takes on additional value as an alternative when proposed for sites near strip mining areas or wastelands.

Sludges may contain pathogenic bacteria or viral organisms. Digestion or some form of pasteurization or stabilization should be a prerequisite to land spreading in order to minimize the potential health hazard. Such pretreatment of sludge should reduce insects and odor problems associated with land spreading operations and thus should also reduce the potential for conflict with local inhabitants. Some forms of pretreatment (e.g., anaerobic digestion) also reduce the quantity of sludge which must be spread. Land spreading is an excellent disposal alternative for sludges resulting from extended aeration since these sludges undergo stabilization during treatment similar to that resulting from digestion. On the basis of public health considerations, it is generally accepted that crops grown on sludge treated land should be restricted to feed grains or fruits and vegetables which do not contact the soil.

Sludges contain heavy metals which may also pose some threat to public health either through transmission at toxic levels in crops grown on treated land or through leaching into groundwater. The interactions between soil constituents and metals are complex and are not well understood at this time. Consequently, precautions must be taken to protect groundwaters. Sites proposed for land spreading should have at least a five foot soil mantel on top of the water table. Sites should also be free from excessive precipitation and high flood potential. A regular monitoring program should be maintained to continuously follow trends in groundwater quality. Provisions should also be made to protect against uncontrolled surface runoff.

Sludge can be transported from the wastewater treatment facility to the ultimate disposal site by truck or by pipeline. Truck transport is generally the optimum method for plant sizes of 10 MGD or less where required haul distances are less than 100 miles. Pipelines become economical at larger plant sizes and longer transport distances. A more complete discussion of transportation costs can be found in Appendix B.

When contemplating instituting a land spreading program, municipalities must consider the availability of land, the time frame within which that land can be leased or otherwise controlled, and potential alternative sites. Should public pressure or public health considerations cause termination of land spreading activities, municipalities must be prepared to undertake interim sludge disposal operations until more acceptable permanent solutions can be devised. Similarly, it must be recognized that land for sludge spreading may well have a finite useful lifetime. Thus, additional land should be available nearby. Gaining access to the large tracts of land is always difficult near urban areas. Hence, land spreading of sludges may not be a realistic alternative for most large metropolitan areas, especially on a long term basis.

When land is to be leased, or sludge is to be sold to private landowners, municipal officials will have to deal with problems of general acceptance. The extra time and costs associated with transporting and spreading sludges, a natural reluctance to work with sewage sludge, and the limited nutrient value compared to commercial fertilizers may make it difficult to sell sludge to farmers. Where sludge spreading is an attractive sludge disposal alternative wastewater officials should therefore have the flexibility to offer additional incentives. These would be most effective in the form of indirect subsidies such as free delivery of bulk lots of processed sludge and low cost rental of spreading devices. Municipalities should also consider the possibilities for nutrient enrichment of sludges to enhance their value to the farmer. This form of activity could be handled in conjunction with a private fertilizer concern.

Incineration

Incineration can be an economical and environmentally acceptable procedure for disposal of sludge. The major advantages of sewage sludge incineration are:

- it produces a sterile, chemically and biologically inert ash which is easily disposable;
- it significantly reduces the volume of waste for ultimate disposal.

The primary disadvantages of incineration are:

- it has high capital and operating costs;
- it is a potential source of air pollution through gas and particle emission and malodor production;
- it usually requires supplemental fuel;
- it is not always easy to sustain proper operation.

Incineration systems are subject to marked economics of scale. Smaller wastewater treatment plants do not produce sufficient quantities of sludge to realize the lower unit sludge disposal costs associated with large furnaces. Primary plants, due to EPA use restrictions, do not approach sizes that warrant incineration facilities. Incineration of sludge from activated sludge and trickling filter plants, on the other hand, appear to become competitive when the plant processes more than 10 MGD.

The costs associated with disposal of ash from incineration processing are small in comparison to the operational costs involved in the incineration process itself. However, these costs must be included as part of the original basis for selection of a sludge disposal option.

Atmospheric emissions from incinerators may cause environmental problems. The size and quantity of particulate emissions from an incinerator vary greatly and depend on such factors as the character of the sludge being fired, incinerator operating conditions, and completeness of combustion.

Complete combustion to produce the principal end products of CO_2, H_2O and SO_2 is costly. In addition, SO_2 emissions must be minimized since SO_2 is toxic and corrosive. Incomplete combustion is unacceptable since the intermediate products formed, such as hydrocarbons and carbon monoxide, are objectionable. Smoke and gases contribute to overall air pollution through reduction in visibility and through their tendency to enter into smog-forming photochemical reactions in the atmosphere. Stack gases must be cooled so that the plume produced will dissipate upon entry into the atmosphere. Care must be taken to prevent plume condensation which would violate equivalent opacity regulations even though the plume may be white in color.

Odor problems may be associated with poorly designed and/or operated sludge incinerators. Odors generally emanate from raw sludge thickening or storage tanks, vacuum filtration units, sludge incinerators and dryers. The basic requirements for preventing odor are good plant design and operation. Septicity of sludge can be prevented by providing adequate sludge hoppers and flexibility in pumping schedules.

The incinerators investigated in this study were designed to meet all present emission standards. In the future, standards will probably be set for discharges of individual materials such as the metals, and monitoring programs must be instituted to assure compliance. Additional work will be required to characterize the nature of other toxic materials such as chlorinated hydrocarbons and carcinogenic agents which may be present in stack gases.

The two important factors that affect the auxiliary fuel requirements are the heat value of the sludge and the heat required for adequate burning. Adequate burning refers to the heat required for complete incineration of the sludge with elevation of the temperature of the gases to a sufficient level to assure odor control. The magnitude of the temperature requirement depends upon the nature of the sludge being burnt, but the minimum deodorizing temperature for conventional incineration units has been established at 1350-1400°F.

The heat required for the incinerator system depends primarily on the efficiency of burning and the degree of excess air required. The following constitute the total heat requirements:

- heat required in raising the temperature of sludge from about 60°F to 212°F; evaporating water from sludge; and increasing the temperature of dried volatiles to the ignition point;
- heat required to raise the temperature of the exhaust gas to the deodorizing temperature;
- heat required to raise the temperature of the air supply required for burning plus the excess air;
- heat losses due to radiation;
- cooling air losses; and
- heat required for other endothermic reactions taking place.

As an example, a ton of sludge at 30 percent solids with a heat content of 10,000 Btu per ton may require 60,000 additional Btu for incineration.

In the incinerator the sludge solids must draw sufficient heat from the surroundings to reach kindling temperature before combustion can occur. When the heat released is sufficient to replace the amount withdrawn, combustion will be maintained. When the quantity of heat released is insufficient to maintain combustion temperature at deodorizing level, heat is recovered from the stack gases and reused, or heat is supplied from an outside source. The latter solution generally represents dedication of energy to destruction of sludge solids with no recovery of the energy for other beneficial uses.

Plant sizes, and therefore quantities of sludge produced per day, dictate the type of incineration equipment most applicable. For plants producing less than 500 lb/hour of sludge, the cyclonic reactor incineration process appears most economical and operational. However, incineration of sludges at a plant of this size (less than 10 MGD) may not be the least cost alternative. For treatment plants in the range of 10 to 100 MGD, the multiple hearth system appears to be most appropriate. Plant sizes approaching 1 BGD may find that economics will prescribe the use of rotary kiln incinerators. The capital investment in rotary kiln incineration at large plants can be substantially lower than an equivalent multiple hearth operation. However, before the above can be realized, operational problems with the rotary kiln which cause the sludge to form large balls must be overcome. A more detailed discussion of the considerations leading to these conclusions is contained in Appendix B of this report.

The addition of sludge producing tertiary processes does not necessarily change this balance, since chemical tertiary sludges are typically treated separately. The economic threshold for these plants can be reduced, however, if the incineration facility is designed to handle the combined organic and chemical sludges. This practice may preclude recalcination of chemical sludges. Chemical and organic sludges can also be treated alternately in the same facility on a campaign basis.

Smaller activated sludge plants or primary and trickling filter plants can achieve economic incineration if some form of regionalization is attempted. This may be accomplished through construction of a central incineration facility serving several municipalities.

There is no question that incineration is the major energy consuming sludge disposal option. In addition, it offers no real opportunities for the reuse of resources contained in the sludge. On the other hand, it involves only a minimal requirement for land. The facility itself is quite small, and only a portion of the solids remain afterwards for ultimate disposal (approximately one third of the dry weight of organic sludges remain as ash). Thus, the decision for construction of an incinerator to dispose of sludges will be influenced greatly by the relative abundance or scarcity of land and energy. Where these influences fail to differentiate a clear choice, the potential for or lack of potential for resource reclamation opportunities should be an important factor in considering alternatives other than incineration.

Ocean Disposal

The oceans have always served as the ultimate disposal sink for all the waterborne waste material carried by the natural and manmade streams discharging at their shores and for all the atmospheric pollutants scrubbed from the air by rain. In addition, with increasing frequency in this century, sewage sludges and hazardous waste materials have been deliberately shipped out to sea and dumped as either an expedient or an economically attractive disposal technique.

The practice of barging municipal sewage treatment sludges to the ocean for dumping, or piping them offshore for discharge has recently received close scrutiny. Experience in the New York Bight area suggests that improper operation of this disposal practice can lead to the sterilization of entire zones in the ocean as well as other undesirable ecological effects. Ocean disposal, however, is economically attractive for large urban areas located on coastal regions.

In 1973 the U.S. Environmental Protection Agency (EPA) established new criteria governing ocean disposal practice. Ocean dumping became illegal on or after April 23, 1973, under the Marine Protection, Research and Sanctuaries Act as adopted in 1972. Exemptions, which also regulate acceptable methods of ocean dumping, will be granted by permit from EPA. Authorization to dispose of wastes by this method is dependent upon, but not limited to, the following:

- the need for proposed disposal;
- the effect of such disposal on human health and welfare (including economic, aesthetic, and recreational values);
- the effect on fish resources, plankton, shellfish, wildlife, shorelines and beaches;
- the effect on marine ecosystems, particularly with respect to
  1. the transfer, concentration, and dispersion of such materials and byproducts through biological, physical, and chemical processes,
  2. potential changes in marine ecosystem diversity, productivity, and stability, and
  3. species and community population dynamics;
- the persistence and permanence of the effects of the dumping;
- the effect of disposal of particular volumes and concentrations of such materials;
- appropriate locations and methods of disposal or recycling, including land-based alternatives and the probable impact of such alternate locations or methods upon considerations affecting the public interest; and
- the effect on alternate uses of the oceans, such as scientific study, fishing, and other living and nonliving resource exploitation.

In designating recommended sites for ocean disposal, the Administrator is constrained to utilize wherever feasible locations beyond the edge of the continental shelf.

EPA approval to dump is being based on a case by case evaluation of each application. In addition to submitting evidence that the materials he wishes to discharge are in compliance with extensive requirements set forth in the legislation, the applicant must also provide supportive data that the dumping of materials in proposed quantity and quality will have no adverse effects on the ocean environment.

The major potential problems associated with disposal of sludges in the ocean can be attributed to the biochemical oxygen demand of the sludges and to pathogenic organisms and toxic substances present in the sludges. These problems can be minimized with digestion or pasteurization of all sludges prior to discharge. Similarly, the consequences of these potential effects can be reduced through proper selection of disposal sites. All sites should be studied carefully before approval. One of two conditions should be sought: 1) sufficient currents to insure rapid and complete dispersal of the solids over a sufficient area of the ocean floor to prevent excessive buildups in any one particular area, or 2) deep unproductive segments of the ocean where sludges can be deposited with little possibility of contact with ocean life or transmittal to other active areas of the ocean. It is also essential that a monitoring program be maintained to follow any changes in water quality or movement of deposited solids.

Ocean disposal, like incineration, makes no attempt to recover potential resources contained in organic sludges. Rather, all control and recoverability is relinquished. This, as in the case of incineration, is countered by a minimization of requirements for land. The energy requirements are not as easily definable since they will depend on the distance between the wastewater treatment plant and the disposal site, and the means of transportation employed.

Ocean disposal of sludge has a number of advantages for seacoast cities when compared with other disposal methods:

- the removal of sludge from the treatment plant is complete, not even an ash residue remains;
- disposal of sludge at sea is relatively inexpensive; and

- assuming the sludge is digested, ocean disposal permits flexibility in plant operation since problems with sludge volume fluctuations are reduced and the dumping schedule can be varied.

Long term effects of ocean disposal of sludges have not been fully established, so surveillance is needed in areas where this disposal method is practiced.

Before a decision is made to use the sea for dilution, beneficial uses of the water should be evaluated in addition to the biologic, geologic, and oceanographic characteristics of the disposal area. Then, decisions can be made concerning the degree of sludge treatment required and the best location for outfalls or barging dumps. Once adopted, a control method is required to assure that the sludge is being dumped in the prescribed location.

Current regulatory agency attitude toward ocean disposal indicates that regulation of ocean disposal practice will be strict and that elimination of the practice may be forthcoming.

Sanitary Landfill

The use of landfills and more recently sanitary landfills is a commonly employed practice for the disposal of sludges. The development of the operational practices which distinguish sanitary landfills from their predecessors (open dumps) has greatly increased the acceptability of landfill disposal.

As with other sludge disposal options, sanitary landfill has associated potential public health problems stemming from the presence of pathogenic organisms in sludges. This threat to public health is best minimized through mandatory digestion, stabilization, or pasteurization of all sludges proposed for burial. Digestion will also help prevent the generation of objectionable odors and gases.

Many of the considerations that must be taken into account in evaluating the land spreading option such as protection of groundwaters are pertinent to the discussion of sanitary landfills. Typically, however, sanitary landfills are better protected against problems resulting from surface runoff, and uptake by crops is generally not a prime consideration. Further, sanitary landfill obviously requires less land than land spreading.

The trade-off required to obtain this added protection and decreased land requirement is the loss of most of the advantages of resource recovery realized in land spreading. Landfill offers little more than the use of a solid material to fill natural depressions or replace soils or gravel that can be used elsewhere. Areas where landfill has been practiced can be reclaimed for recreational or other purposes. No studies have been conducted to assess any added benefits to soil fertility that might be attributed to the prior use of land for sanitary landfills. The minimum two foot overlayer of soil would probably minimize these effects.

The potential danger of ground or surface water pollution by landfill leachates cannot be overlooked. Solid wastes, especially raw sewage sludges, ordinarily contain contaminants and infectious materials. Serious public health problems can result if pollutants enter water supplies. Proper landfill site selection and good engineering design can minimize this danger.

The selection of sanitary landfill as a disposal option requires that availability of inexpensive land with a sufficiently deep water table (five feet or more below the excavation). The land must be dedicated to the use for at least the lifetime of the operation since cropping or other productive activities cannot be conducted coincident with disposal as in the case of land spreading. Similarly, sufficient additional land must be available for use in the foreseeable future since repeated use of the same plots is not feasible in the short term. These restraints minimize the usefulness of landfills to larger metropolitan areas. The practice may be attractive in areas where municipal solid wastes are placed in landfills since joint processing of the two wastes can result in lower unit costs.

Recalcination

Recalcination is an attractive sludge disposal option for chemical sludges resulting from lime clarification of wastewaters.

Recalcination is subject to many of the considerations that must be made in selecting incineration options in general: very high capital costs for small plants, potential added costs for additional emission control devices that may be required in the future, unknown emission of potentially harmful hydrocarbons, high energy requirements, and low land usage. The potential for recovery of a useful coagulant adds another dimension to the evaluation.

It is true that in many cases recalcining lime may not be less expensive than purchasing new chemical. The tradeoff is more than just one of costs; however, reuse of lime through recalcination reduces the demands on both limestone deposits and land required for the disposal of ash. Blowdown from recalcination may represent approximately one half of the quantity of ash that would be produced from conventional incineration. Furthermore, recalcination of lime sludges reduces the dependency of a treatment plant upon a supply of chemicals and thus may reduce the necessity to maintain a large lime inventory at the treatment plant. These advantages are gained at the expense of additional energy needed to produce the required temperatures. Thus, recalcination intensifies the sludge option tradeoff between land and energy.

There may not be as many options available for disposal of lime-based chemical sludges as there are for organic sludges. The increased pH and alkalinity eliminate the potential for digestion. Hence, pasteurization or further stabilization should be required before landfill, ocean dumping, or landspreading should be attempted. The ramifications of these courses of action have not been sufficiently investigated to render these alternatives acceptable at this time. In light of this, recalcination appears the best option for disposal of lime-based chemical sludges from plants larger than 10 MGD. While neither recalcination or incineration are economical for smaller plants, incineration is the more practical of the two. The desirability of either option will also be dependent on the exact nature of the chemical sludge. Lime sludges will differ as a function of where in the process and how they are generated. Sludges from physical-chemical processing, such as that found in Strategy #10, will have a high organic content, while those from lime addition (after activated sludge treatment such as found in Strategy #8) will largely be calcium carbonate. The level of organic content will influence the disposal options available and their ultimate efficiency.

TREATMENT AND DISPOSAL PROCESS PROFILES

INTRODUCTION AND INSTRUCTIONS

The process profile sheets contained in this section are designed to present comparative data on the liquid treatment strategies and sludge treatment options evaluated during the study reported herein. Individual parameters employed were selected for their ability to display the characteristic inputs and outputs of these systems. Comparison with processes not included in this study must be undertaken cautiously with a full understanding of the assumptions made for the purposes of this study as outlined in Appendices A and B.

Two slightly different formats were utilized in the presentation of the strategies. Strategies #1 through #7, and #11 utilized the profile sheet format which contains no chemical sludge handling option column due to its inapplicability. Chemical sludges are generated in Strategies #8 through #10 and four chemical sludge handling options were considered for each of these strategies. However, only one chemical sludge option is presented per profile sheet so that the organic sludge option columns can be compared on an economic basis. Hence, for any one plant size and liquid treatment combination, four separate profile sheets are included in order to present the chemical and organic sludge handling options analyzed for strategies #8 through #10.

The numerical figures presented represent general values that apply for municipal wastewater treatment plants located in temperate regions. The running totals listed below the organic sludge option columns include the complete costs of the liquid treatment strategy, the chemical sludge option (if applicable) and the particular organic sludge treatment option being analyzed. Therefore, each running total appearing under the various sludge options is independent of any other sludge handling scheme and can be directly compared with the remaining seven options.

A total of twelve distinct sludge handling and disposal systems were considered in this work. Each of these systems is comprised of a series of several of the unit operations described in Appendix B. These twelve systems do not constitute all feasible methods of sludge handling and disposal; however, they are considered to be representative of the major systems presently in use and those which are likely to be in use during the next decade.

Several general assumptions relative to each unit operation were required to facilitate the development of operational and cost parameters. These general assumptions are presented with the unit operation descriptions in Appendix B.

For the sizing and cost purposes of this report, 1000 MGD size facilities were treated as being ten times the size of a 100 MGD facility, except for pipeline transport of sludge, where the economics of increased size can readily be calculated. In practice there may be some decrease in costs with increased size; however, the economics of scale for 1000 MGD size facilities are uncertain and, therefore, no attempt was made to report them herein. Unit operations such as vacuum filtration, centrifugation, Porteous heat treatment, and anaerobic digestion are all limited by size and/or period of operation. After a specific size, or operational period, is exceeded, multiple units are required to process increased volumes of sludge. In the case of a 100 MGD plant, most treatment units have already reached their physical and operational limits and, therefore, direct extrapolation of their cost and operational parameters is justifiable.

Eight separate organic sludge handling schemes were considered. Each sludge handling scheme was evaluated for the various combinations of sludge types and quantities in order to assess the economic and operational feasibility of each option and to establish base values for comparing one option against another. As was expected, several of the handling schemes were found to be infeasible for certain plant sizes and/or sludge types.

In the cases where organic sludges were produced from more than one treatment operation, the organic sludges were combined and handled as a single sludge stream. This simplification was also extended to the chemically (alum) precipitated biological sludge of wastewater treatment strategy number seven. However, chemical sludges from the tertiary and physical-chemical liquid treatment Strategies #8, #9, and #10 were handled separately.

Four separate chemical sludge options were evaluated for handling the massive chemical sludges produced by the physical-chemical processes of treatment Strategies #8, #9, and #10.

The recalcinated product represented approximately eighty percent (by weight) of the initial sludge collected and twenty-five percent of the recalcined lime was wasted in order to prevent excessive phosphate return to the treatment plant system or the buildup of inert ash residue in the system. An equivalent amount of makeup lime was provided to replace the amount wasted.

The chemical sludge handling capital and operating cost figures, as well as the physical parameters, indicated on the profile sheets for gravity thickening, vacuum filtration, centrifugation, and sanitary landfill are all based upon the same data reported in the organic sludge unit operations descriptions given in Appendix B.

Recalcination and/or incineration of lime sludges differs only slightly from the organic sludge incineration process and is described in Appendix B.

Overall performance of a particular sludge option is dependent upon the operational efficiency of each individual unit operation in the sludge handling sequence. Should the efficiency of any one unit decline, the characteristics of the sludge leaving that unit will change and cause subsequent disruption of the performance of succeeding units.

DATA SOURCES

References were not included on the profile sheets so as to reduce the potential for confusion. The applicable references have been tabulated by unit process and unit operation and are numerically presented in Tables IV and V. Complete descriptions of each reference follow the profile sheet presentation.

LEGEND

Figure 27 contains a legend to assist the reader in utilizing the profile sheets. The number designations in this figure are keyed to numbers in Table VI which contains detailed explanations of the specifics involved in the development of the rows and columns of the profile sheets.

TABLE IV

DATA SOURCE REFERENCES FOR LIQUID TREATMENT PROCESSES

	Primary	Activated Sludge	Activated Sludge with Chem Add	Trickling Filter	Waste Stabilization	Extended Aeration	Nitrification Denitrification	Coagulation Filtration	Clarification Carbon Sorption Zeolite	Carbon Sorption	Land Disposal	Surface Water Disposal
Inputs												
Energy	13	13	13	13	13	13	22	23	5,23	23	5	
Concrete	19,76	19,76	19,73	19,76	76	19,66	19,20,41,73	4,24,74	4,12,74	4,74	76	76
Steel	19,76	19,75	19,73	19,76	19,76	19,66	19,20,41,73	4,24,74	4,12,74,76	4,74,76	76	76
Chemicals			16				16	4	4,12,18	4	19	19
Land	5,9	5,9	2	9,20	26	9	5,9	5,9	5,9	5,9	1	10
Labor	13	52	52	52	52,54	13	52	23	23	23	203	
Outputs												
BOD	3,6	1	1	1,20	2,6	1	16	5,21	11	5	1	
Suspended Solids	3,6	1	1,16	1	31	1	16	11	11	5	1	
Nutrients	3,6	1	1	1	31	1	16	21	11,12	5,17	1	
Toxic Substances		1	1	1		1	55				1	
Sludge	1	1,3	22,31	1		1,31	22,47	4,21	4,21			
Safety	177	177	177	177	177	177	177	177	177	177	177	
Nuisance									[illegible]	28	1	
Costs												
Capital	9	9,13	9,20	9	54	66	17	21	4,21,178	9	41	9
Operating	9	9,13	9	9	13	13	15,16	21	4,21,178	9	66	9

TABLE V

DATA SOURCE REFERENCES FOR SLUDGE PROCESSING OPERATIONS

	Gravity Thickening	Flotation Thickening	Porteous	Centri-fuge	Vacuum Filtration	Inciner-ation	Chemical Conditioning	Diges-tion	Land-Fill	Ocean Disposal	Land Spreading	Sand Drying
Inputs												
Energy				29,210	60,211	4	74	19	19		19	19
Concrete & Steel	19,75	19	76	74,75	75	4,74,76		19				
Chemicals		7					10,20,61					
Land	4	64			19			63	65		10	31
Labor	52	52		52,54	52,54	52,54		52,54	65	72	1	52
Outputs												
Nutrients						10			65	10	68	
Atmospheric Emissions						212						
Sludges	1,5,10, 22,31	7,10, 20,55	10	20,51, 53,55	20,31,55			10,31	65	10	31	31,56
Costs												
Capital	53,64	7,10	62	29,54,60	10,29,54	54,62		54	70	67	68	54
Operating	10	7,10	7,59,62	4,10	10,60	3,10,54	7,10,60	10	70	67	68	10

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 32. AT A FLOW RATE OF 33.

	LIQUID TREATMENT					38. CHEMICAL SLUDGE OPTION	39. ORGANIC SLUDGE TREATMENT OPTIONS							
	34. PRIMARY	35. SECONDARY	36. TERTIARY	37. LIQUID DISPOSAL	45. UNIT OPERATION	44.	1	2	3	4	5	6	7	8
					40. THICKENING :	GRAVITY								
					41. CONDITIONING :		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					42. DEWATERING :	VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					43. DISPOSAL :	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS														
1. ENERGY (UNITS/DAY)														
2. CONCRETE (CU YDS)														
3. STEEL (TONS)														
4. CHEMICALS (LBS/DAY)														
5. LAND (ACRES)														
6. LABOR (MAN YRS/YR)														
OUTPUTS														
7. BOD (MG/L)														
8. BOD (LBS/DAY)														
9. SUSPENDED SOLIDS (MG/L)														
10. SUSPENDED SOLIDS (LBS/DAY)														
11. NUTRIENTS: P (MG/L)														
12. (LBS/DAY)														
13. N (MG/L)														
14. (LBS/DAY)														
15. HEAVY METALS (LBS/DAY)														
16. ATMOSPHERIC EMISSIONS (LBS/DAY)														
17. SLUDGES - % SOLIDS														
18. TOTAL DRY WT. (LBS/DAY)														
19. SOLID WASTE (CU FT/YR)														
20. NUISANCE - ODOR														
21. NOISE														
22. TRAFFIC														
23. SAFETY (INJURIES/10^6 MAN-HRS)														
COSTS														
24. CAPITAL ($ x 10^6)														
25. RUNNING TOTAL CAPITAL ($ x 10^6)														
26. LAND ($)														
27. RUNNING GRAND TOTAL ($ x 10^6)														
28. OPERATING (¢/1000 GAL)														
29. 13% AMORTIZED (¢/1000 GAL)														
30. TOTAL OPERATING (¢/1000 GAL)														
31. RUNNING TOTAL (¢/1000 GAL)														

FIGURE 27. PROFILE SHEET LEGEND

TABLE VI

SPECIFICS OF PROCESS PROFILE SHEET LEGEND

1. Energy in units/day gives the average daily use of electrical power and natural gas or fuel oil. When references gave overall electrical costs, a unit cost of 2¢/kwh was assumed. The numerical values displayed on the profile sheets for electrical energy usage may vary ±15 percent and the thermal energy values may vary ±20 percent.

2. Concrete in cu yds gives the total requirement for basins, channels, structures, and foundations. Estimates were largely made from design criteria. The concrete was not allocated for buildings other than the foundation. The numerical values displayed on the profile sheets may vary ±20 percent among installations.

3. Steel in tons gives the total requirement for structural steel, piping, and steel in various equipment items. Estimates were largely based on design criteria. The numerical values displayed on the profile sheets may vary ±20 percent among installations.

4. Chemicals in lbs/day gives the average daily requirement for reagents. The sludge conditioning chemicals were assumed to be organic polymers.

5. Land in acres specifies the spatial requirement for the treatment process selected. In the case of spray irrigation or land spreading, the requirement may occur periodically as parcels of land are exhausted. For other strategies, the land requirement occurs only at the outset and does not change unless the plant size is changed. The land figures appearing in the secondary treatment column include both secondary, primary and administration building requirements, where applicable.

6. Labor in man years/year denotes the manpower requirement for individual processes. The figure includes administrative personnel, laboratory assistants, supervisory personnel, and operating and maintenance labor. A man year of labor was estimated to be equivalent to 2080 hours/year. The man hours required for disinfection appear in the liquid treatment figures.

7. BOD in mg/l refers to the biochemical oxygen demand of the effluent from the stated process.

8. BOD in lbs/day refers to the total daily biochemical oxygen demand represented by the effluent level listed in 7.

9. Suspended solids in mg/l gives the concentration of undissolved particulate matter in the effluent from the stated process.

10. Suspended solids in lbs/day gives the total daily quantity of particulates represented by the effluent level given in 9.

11. Nutrient P in mg/l gives the concentration of phosphorus present in the effluent of the stated process.

12. Nutrient P in lbs/day gives the total daily quantity of phosphorus represented by the effluent concentration given in 11. The values indicated under the sludge handling option columns represent the total quantity of phosphorus reaching the sludge handling equipment. The fractional distribution of phosphorus contained in the sludge is indicated on Figure 25-B.

13. Nutrient N in mg/l gives the concentration of nitrogen present in the effluent of the stated process. Nitrogen may be present as ammonia, nitrate, nitrite, or organic nitrogen.

14. Nutrient N in lbs/day gives the total daily quantity of nitrogen represented by the effluent concentration given in 13. The values indicated under the sludge handling option columns represent the total quantity of nitrogen reaching the sludge handling equipment. The fractional distribution of nitrogen contained in the sludge is indicated on Figure 25-D. The only exception is the incineration process where the total quantity of nitrogen has been assumed to be released into the atmosphere as nitrogen and nitrogen oxides. The nitrogen oxide quantities are indicated under atmospheric emissions.

TABLE VI (Cont'd.)

15. Heavy metals in lbs/day gives the total daily combined quantity of the heavy metals in the effluent of the stated process. The values indicated under the sludge handling option columns represent the total quantity of heavy metals reaching the sludge handling equipment. The fractional distribution of heavy metals contained in the sludge is indicated in Figure 25-C. The only exception is that quantity which is discharged in the incineration process as particulate matter. This quantity appears under the row entitled "Atmospheric Emissions."

16. Atmospheric emissions in lbs/day gives the total daily emissions from incineration or recalcination options. Other treatment options were considered to have no atmospheric emissions.

17. Sludges in % solids reflect the solids concentration of the sludges produced by the process.

18. Total dry wt in lbs/day gives the total daily quantity of solids contained in the sludges listed for item 17.

19. Solid waste in cu ft/yr gives the annual volume of solid wastes resulting from spent chemical containers. The figures presented assume the use of bags for chemical delivery. It was also assumed that 150 bags equals one cubic yard of solid waste. Delivery of chemicals in barrels was considered as an option. The barrels were assumed to be returnable.

20. Odor reflects a subjective evaluation of the threshold at which odors become frequent and annoying. Processes or unit operations known to apply to the preceding criteria were labeled as "potential" violators. All other processes were assumed not to be offenders.

21. The level of noise was subjectively evaluated due to its inherent dependence upon length of exposure as well as decibel level. This category essentially reflects potential effects upon plant employees. Processes known to be noisy were evaluated as "ABOVE AVERAGE" offenders depending upon plant design.

22. Traffic reflects the number of trips per day necessitated by a truck capable of hauling 20 tons of sludge from the plant plus the traffic involved in supplying plant chemical needs. Trips necessary to meet total liquid treatment chemical requirements appear in the liquid disposal column.

23. Safety reflects the number of lost-time accidents normally occurring in a treatment plant per million man hours worked. These figures are only specific to treatment plants and not to types of plants. Only one figure is reported for the strategy considered.

24. Capital cost in $\$ \times 10^6$ gives the total initial investment required for the stated option in millions of dollars. The figure includes all equipment and facilities at an installed cost, but does not include the cost of land. All costs are given in 1973 dollars. When recent data was not available, older costs were adjusted with a five percent annual inflation factor. The costs involved in chlorination preceding land application are included in the land application cost figures.

25. Running total capital cost in $\$ \times 10^6$ gives the total capital costs in millions of dollars for the stated treatment process and all previous unit processes in the given strategy. All provisions for item 24 are maintained. The final running totals appearing in the organic sludge option columns are independent of the other sludge options. Therefore, they can be directly compared.

26. Land cost in $ gives the cost of land required for the stated unit process at an assumed land value of $1000/acre. The effect of different land value patterns can be determined through use of the work sheets presented later in this report.

27. Running grand total cost in $\$ \times 10^6$ gives the total capital and land costs in millions of dollars for the stated treatment process and all previous unit processes in the given strategy. All provisions for items 25 and 26 are maintained.

TABLE VI (Cont'd.)

28. Operating cost in ¢/1000 gal gives the average daily cost for treating 1000 gallons of influent. These costs include power, fuel, chemicals, labor, maintenance, and supervision.

29. 10% amortized cost in ¢/1000 gal gives the amortization cost of the capital expenditures other than land for the stated process per 1000 gallons of influent treated. A 10% rate and 20 year facility life are assumed for amortization purposes. This figure may be considered as a replacement fund cost or as payment on bonds utilized to build the original facility.

30. Total operating cost in ¢/1000 gal gives the total cost for the stated process per 1000 gallons of influent treated. This cost is the sum of the individual components listed in items 28 and 29.

31. Running total operating cost in ¢/1000 gal gives the total cost for the stated process and all preceding unit processes per 1000 gallons of influent treated. This total is the cumulative sum of costs presented in item 30.

32. Treatment Strategy # identifies the strategy being profiled on the sheet. Individual strategies are described and illustrated in an earlier section of this report.

33. Flow Rate identifies the size of facility for which the strategy profile is valid.

34. Primary treatment is prescribed for certain strategies. A complete description of primary treatment as a unit process and the assumptions upon which figures presented in the profile sheets are based can be found in Appendix A. When primary treatment is not prescribed for the strategy of interest, this column is left blank. References for data presented in this category can be found in Table IV.

35. Secondary treatment is prescribed for several strategies. A complete description of the secondary unit processes employed and the assumptions upon which figures presented in the profile sheets are based can be found in Appendix A. The heading entered at the top of this column denotes the particular unit process being specified. References for data in this column can be found in Table IV.

36. Tertiary treatment is prescribed for several strategies. A complete description of the tertiary unit processes employed and the assumptions upon which figures presented in the profile sheets are based can be found in Appendix A. The heading entered at the top of this column denotes the particular unit process being considered. When more than one tertiary process is specified, the values given in the column represent the sum of the values for each process. References for data given in this column can be found in Table IV.

37. All strategies considered include discharge of a liquid effluent. A complete discussion of disinfection and land application can be found in Appendix A. The nutrient, BOD, and solids values presented here represent the effluent quality for the strategy as a whole. The ratio of these numbers to the influent levels described in the introduction is equivalent to the projected removal efficiency for the stated strategy. References employed to obtain the data given in this column can be found in Table IV.

38. The chemical sludge option column only appears on the profile sheets describing (numerically) treatment Strategies #8, #9, and #10. Furthermore, only one chemical sludge option is presented per profile sheet and, therefore, applies for all the chemical sludge handled within the strategy. The running totals (both capital and operating) for the organic sludge options reflect the addition of the cost for chemical sludge handling. Hence, the numerical totals appearing in the organic sludge option columns reflect a total cost for treating the wastewater influent and handling

TABLE VI (Cont'd)

both the chemical and organic sludge. The various subheadings in this column identify the unit operation segments of the option being considered. A description of the option and assumptions utilized in constructing the profile have been previously discussed. Descriptions of individual unit operations can be found in Appendix B.

39. Eight organic sludge treatment options are presented for the primary and secondary sludges produced in various strategies. The subheadings in each column identify the unit operations employed for each option. A general description of the options and assumptions utilized in constructing the profile sheets have been previously presented. Descriptions of individual unit operations can be found in Appendix B. Not all organic sludge options are recommended for each liquid treatment strategy as previously noted.

40. The thickening unit operation consisted of either gravitational or dissolved air flotation. The references utilized in developing the numbers appearing on the profile sheets are numerically listed under the appropriate subheading in Table V. The particular thickening process utilized is indicated for each sludge option on all profile sheets.

41. Conditioning consisted of either chemical or Porteous heat treatment. The appropriate method is indicated in the profile sheets for each sludge option. The references utilized in developing the numbers appearing in the profile sheets are numerically listed under the appropriate subheadings in Table V.

42. Dewatering techniques utilized include vacuum filtration, centrifugation and sand drying. The references utilized in developing the numbers appearing on the profile sheets are numerically listed under the appropriate subheadings in Table V.

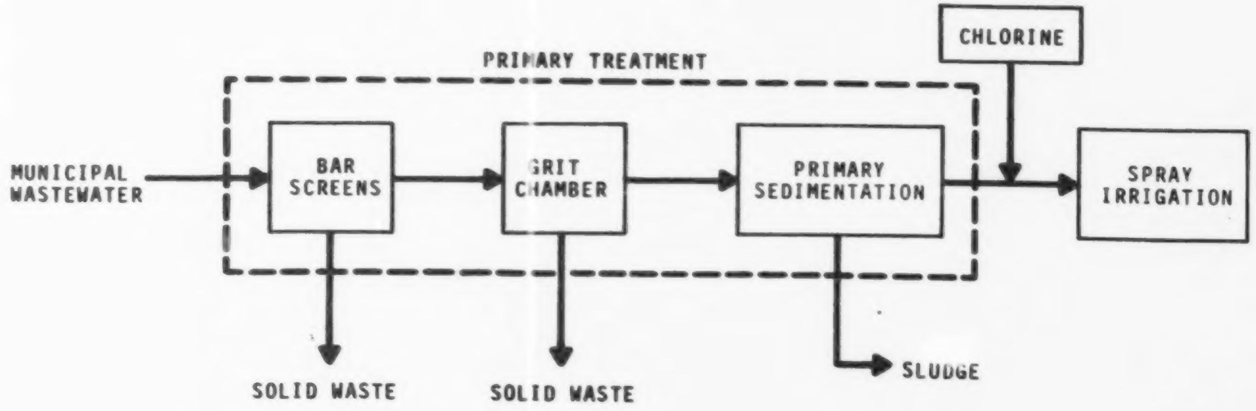
43. Ultimate disposal methods analyzed include recalcination and sanitary landfill alone, landspreading (pipeline or truck transportation) or ocean dumping (pipeline or barge). The references utilized in developing numbers appearing on the profile sheets are numerically listed under the appropriate subheading in Table V.

44. The numbers appearing in this row identify the organic sludge options presented in the text of this report.

45. The unit operation column indicates the major category of sludge treatment to be undertaken. The specific unit operation utilized can be read left to right through the sludge handling options presented.

PROCESS PROFILE SHEETS FOR TREATMENT STRATEGY # 1

Primary Treatment with Land Application of Liquid Effluent


PRIMARY TREATMENT
CHLORINE
MUNICIPAL WASTEWATER
BAR SCREENS
GRIT CHAMBER
PRIMARY SEDIMENTATION
SPRAY IRRIGATION
SOLID WASTE
SOLID WASTE
SLUDGE

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 1 AT A FLOW RATE OF 100,000 GPD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	1	2	3	4	5	6	7	8
					THICKENING:								
					CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
				Land	DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	110 kwh			120 kwh									
CONCRETE (CU YDS)	22			2									
STEEL (TONS)	2.3			5.5									
CHEMICALS (LBS/DAY)				Cl_2-8.4									
LAND (ACRES)	1.8			12.9									
LABOR (MAN YRS/YR)	.82			.1									
OUTPUTS - BOD (MG/L)	130			2.6									
(LBS/DAY)	104			2.1									
SUSPENDED SOLIDS (MG/L)	80			5.2									
(LBS/DAY)	64			4.16									
NUTRIENTS. P (MG/L)	14.3			.14									
(LBS/DAY)	11.4			.11									
N (MG/L)	32			4.8									
(LBS/DAY)	25.6			3.8									
HEAVY METALS (LBS/DAY)	.4-8.3			Negligibl					DOES				
ATMOSPHERIC EMISSIONS (LBS/DAY)									NOT				
SLUDGES-% SOLIDS	5								APPLY				
TOTAL DRY WT. (LBS/DAY)	108												
SOLID WASTE (CU FT/YR)													
NUISANCE - ODOR	Potential												
NOISE													
TRAFFIC				Negligibl									
SAFETY (INJURIES/10^6 MAN-HRS)	15			Pathogens Last 1 mo									
COSTS - CAPITAL ($ x 10^6)	.090			.039-.057									
RUNNING TOTAL CAPITAL ($ x 10^6)	.090			.129-.14									
LAND ($)	1800			12,900									
RUNNING GRAND TOTAL ($ x 10^6)	.092			.144-.162									
OPERATING (¢/1000 GAL)	8			5-9									
10% AMORTIZED (¢/1000 GAL)	29.5			16.7-22.5									
TOTAL OPERATING (¢/1000 GAL)	37.5			21.7-31.5									
RUNNING TOTAL (¢/1000 GAL)	.7.5			59.2-69									

Primary Treatment - 100,000 GPD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 1 AT A FLOW RATE OF 1 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL Land	UNIT OPERATION	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY		GRAVITY	GRAVITY	GRAVITY		GRAVITY	GRAVITY
					CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	250 kwh			800 kwh		50 kwh 4.6x10^6 Btu	63 kwh 2.3x10^6 Btu	39 kwh 2.2x10^6 Btu	2.5 kwh	2.5 kwh	Not Practical	17.5 kwh	17.5 kwh
CONCRETE (CU YDS)	98			41		12	11	20	120	120		122	122
STEEL (TONS)	9.6			22.7		28	27	40	14 /	14		16	16
CHEMICALS (LBS/DAY)				Chlorine-84		5-8	2.7-5.4					4-6	4-6
LAND (ACRES)	3.4			129		.26-.35	.26-.35	.17-.23	.42-.53	3.5-14		.17-.23	.017-.023
LABOR (MAN YRS/YR)	2.6			1		1.7-2.0	1.5-1.6	1.6-1.7	.7-.9	1.1-1.5		1.2-1.5	2.3-2.6
OUTPUTS - BOD (MG/L)	130			2.6									
(LBS/DAY)	1040			21									
SUSPENDED SOLIDS (MG/L)	80			5.2									
(LBS/DAY)	640			41.6									
NUTRIENTS: P (MG/L)	14.3			.14									
(LBS/DAY)	114			1.1		10-30	10-30	10-30	10-30	10-30		10-30	10-30
N (MG/L)	32			4.8									
(LBS/DAY)	256			38					12-45	12-45		12-45	12-45
HEAVY METALS (LBS/DAY)	4-83			.2-1.2									
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=.05-.08 NO_x = .14-.22	SO_2=.05-.08 Particulates=1.7-2.5	HCl=.3-.46					
SLUDGES-% SOLIDS	5					100	100	100	25-50	6-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	1080					320	320	243	750	750		750	750
SOLID WASTE (CU FT/YR)						3.3-5.3	1.2-3.5					2.6-3.9	2.6-3.9
NUISANCE - ODOR	Potential					None	None	None	Potential	Potential		Potential	None
NOISE													
TRAFFIC				Negligible		.008	.008	.006	.019	.019		.019	Negligible
• SAFETY (INJURIES/10^6 MAN-HRS)	19.6			Pathogens Last 1 mo									
COSTS - CAPITAL ($ x 10^6)	.455			.39-.57		.332-.336	.245-.271	.255-.311	.157-.160	.11-.15		202-.205	.659-.663
RUNNING TOTAL CAPITAL ($ x 10^6)	.455			.85-1.03		1.18-1.37	1.1-1.3	1.11-1.34	1.0-1.19	.96-1.18		1.05-1.24	1.51-1.69
LAND ($)	3400			.129x10^6		260-350	260-350	170-230	420-530	3500-14,000		170-230	17-23
RUNNING GRAND TOTAL ($ x 10^6)	.458			.98-1.16		1.31-1.50	1.23-1.43	1.24-1.47	1.13-1.32	1.09-1.32		1.18-1.37	1.64-1.82
OPERATING (¢/1000 GAL)	6			5-9		2.5-3.2	2.2-3	2.1-2.7	1.6-2.3	.77-.93		1.3-1.6	2.4-3.5
10% AMORTIZED (¢/1000 GAL)	14.8			16.7-22.5		10.7-10.8	7.9-8.7	8.2-10	5.1-5.2	4.6-5.3		6.5-6.6	21.2-21.3
TOTAL OPERATING (¢/1000 GAL)	20.8			21.7-31.5		13.2-14.0	10.1-11.7	10.3-12.7	6.7-7.5	5.4-6.2		7.8-8.2	23.6-24.8
RUNNING TOTAL (¢/1000 GAL)	20.8			42.5-52.3		55.7-66.3	52.6-64	52.8-65	49.2-59.8	47.9-58.5		50.3-60.5	66.1-77.1

Primary Treatment - 1 MGD

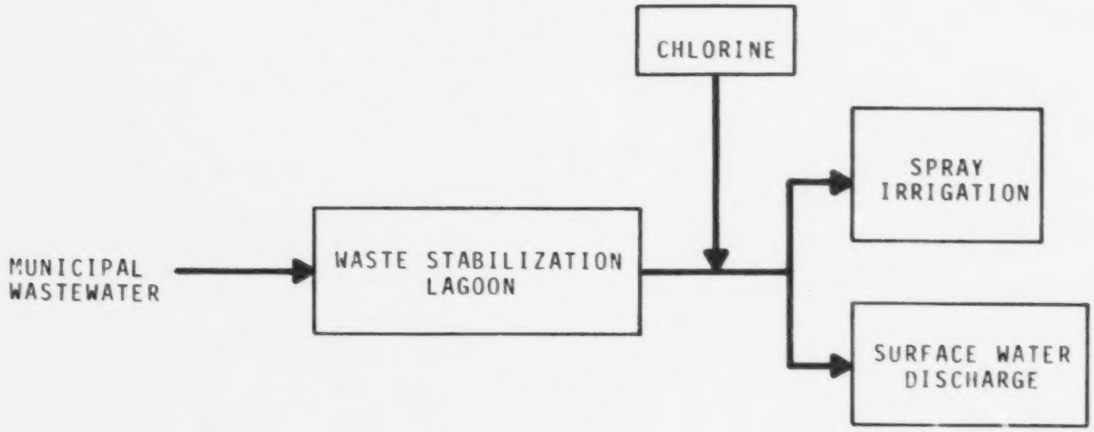
PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 1 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL LAND	UNIT OPERATION THICKENING CONDITIONING DEWATERING DISPOSAL	1 GRAVITY CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 GRAVITY PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 GRAVITY DIGESTION SAND DRYING LANDFILL	5 GRAVITY DIGESTION LAND SPREADING	6 DIGESTION OCEAN DUMPING	7 GRAVITY DIGESTION VACUUM FILTRATION LANDFILL	8 GRAVITY DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270 kwh			4600 kwh		500 kwh $46x10^6$ Btu	436 kwh $23x10^6$ Btu	3[illegible]0 kwh $22x10^6$ Btu	25 kwh	[illegible] kwh	Not Practical	175 kwh	175 kwh
CONCRETE (CU YDS)	756			252		22	20	25	565	565		570	570
STEEL (TONS)	75			66.7		44	42	52	65	65		70	70
CHEMICALS (LBS/DAY)				Chlorine-840		50-80	27-54					40-60	40-60
LAND (ACRES)	10			1290		2.6-3.5	2.6-3.5	1.7-2.3	4.2-5.3	34-137		1.7-2.3	.17-.23
LABOR (MAN YRS/YR)	5.5			10		4.2-5.3	3.2-3.6	3.7-4.8	2.0-2.6	9.6-12.9		2.9-4.0	3.4-4.6
OUTPUTS - BOD (MG/L)	130			2.6									
(LBS/DAY)	10,400			210									
SUSPENDED SOLIDS (MG/L)	80			5.2									
(LBS/DAY)	6400			416									
NUTRIENTS: P (MG/L)	14.3			.14									
(LBS/DAY)	1140			11		100-300	100-300	100-300	100-300	100-300		100-300	100-300
N (MG/L)	32			4.8									
(LBS/DAY)	2560			380					120-450	120-450		120-450	120-450
HEAVY METALS (LBS/DAY)	40-830			[illegible]-12									
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=.5-.8 NO_x=1.4-2.2	SO_2=.5-.8 Particulates=	HCl=.3-4.6 17-25					
SLUDGES-% SOLIDS	5					100	100	100	25-50	6-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	10,800					3200	3200	2430	7500	7500		7500	7500
SOLID WASTE (CU FT/YR)						33-53	12-35					26-39	26-39
NUISANCE - ODOR	Potential					None	None	None	Potential	Potential		Potential	None
NOISE							Above Average						
TRAFFIC				.02		.08	.08	.06	.19	.19		.19	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)	26.5			Pathogens Last [illegible]									
COSTS - CAPITAL ($ x 10^6)	2.21			3.9-5.7		.56-.97	.51-.71	.54-.755	.39-.44	.21-.29		.46-.57	.90-1.01
RUNNING TOTAL CAPITAL ($ x 10^6)	2.21			6.11-7.91		6.67-8.88	6.62-8.62	6.65-8.66	6.5-8.35	6.32-8.2		6.57-8.48-	7.01-8.92
LAND ($)	10,000			$1.29x10^6$		2600-3500	2600-3500	1700-2300	4200-5000	$.34-1.37x10^5$		1700-2300	170-230
RUNNING GRAND TOTAL ($ x 10^6)	2.2[illegible]			7.41-9.21		7.97-10.2	7.92-9.92	7.95-9.96	7.8-9.66	7.65-9.64		7.87-9.78	8.3-10.2
OPERATING (¢/1000 GAL)	4			5-9		1.5-2.2	1.5-2.3	1.3-1.9	1.6-2.2	.77-.93		1.0-1.6	1.1-1.8
10% AMORTIZED (¢/1000 GAL)	7.1			16.7-22.5		1.8-3.1	1.6-2.3	1.7-2.4	1.3-1.4	1.0-1.7		1.5-1.8	2.9-3.3
TOTAL OPERATING (¢/1000 GAL)	11.1			2[illegible].7-31.5		3.3-5.3	3.1-4.6	3.0-4.3	2.9-3.6	1.8-2.6		2.5-3.4	4.0-5.1
RUNNING TOTAL (¢/1000 GAL)	11.1			[illegible].6		36.1-47.9	35.9-47.2	35.6-46.9	35.7-46.2	36.6-45.2		3[illegible].3-46.0	36.8-47.7

Primary Treatment - 10 MGD

PROCESS PROFILE SHEETS FOR TREATMENT STRATEGY # 2

Waste Stabilization Lagoon


MUNICIPAL WASTEWATER
WASTE STABILIZATION LAGOON
CHLORINE
SPRAY IRRIGATION
SURFACE WATER DISCHARGE

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 2 AT A FLOW RATE OF 100,000 GPD

LIQUID TREATMENT

		PRIMARY	SECONDARY Waste Stabilization	TERTIARY	LIQUID DISPOSAL Surface Water
INPUTS -	ENERGY (UNITS/DAY)		270-360 [illegible]		
	CONCRETE (CU YDS)				
	STEEL (TONS)		1		5.5
	CHEMICALS (LBS/DAY)				Cl_2-8.4
	LAND (ACRES)		6		
	LABOR (MAN YRS/YR)		.05-.07		
OUTPUTS -	BOD (MG/L)		40		
	(LBS/DAY)		34		
	SUSPENDED SOLIDS (MG/L)		64		
	(LBS/DAY)		53		
	NUTRIENTS: P (MG/L)		12		
	(LBS/DAY)		10		
	N (MG/L)		32		
	(LBS/DAY)		25.6		
	HEAVY METALS (LBS/DAY)		.4-8.3		.4-8.3
	ATMOSPHERIC EMISSIONS (LBS/DAY)				
	SLUDGES-% SOLIDS				
	TOTAL DRY WT. (LBS/DAY)				
	SOLID WASTE (CU FT/YR)				
	NUISANCE - ODOR				
	NOISE				
	TRAFFIC				Negligible
	SAFETY (INJURIES/10^6 MAN-HRS)		15		
COSTS -	CAPITAL ($ x 10^6)		.047		.0055
	RUNNING TOTAL CAPITAL ($ x 10^6)		.047		.0525
	LAND ($)		6,000		
	RUNNING GRAND TOTAL ($ x 10^6)		.053		.058
	OPERATING (¢/1000 GAL)		1.7		2
	10% AMORTIZED (¢/1000 GAL)		17		1.8
	TOTAL OPERATING (¢/1000 GAL)		18.7		3.8
	RUNNING TOTAL (¢/1000 GAL)		18.7		22.5

ORGANIC SLUDGE TREATMENT OPTIONS

UNIT OPERATION	1	2	3	4	5	6	7	8
THICKENING:								
CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING

DOES
NOT
APPLY

Waste Stabilization - Discharge to Surface Water - 100,000 GPD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 2 AT A FLOW RATE OF 100,000 GPD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Waste Stabilization	TERTIARY	LIQUID DISPOSAL Land	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	1 CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 DIGESTION SAND DRYING LANDFILL	5 DIGESTION LAND SPREADING	6 DIGESTION OCEAN DUMPING	7 DIGESTION VACUUM FILTRATION LANDFILL	8 DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		270-360 kwh		120 kwh									
CONCRETE (CU YDS)													
STEEL (TONS)		1		5.5									
CHEMICALS (LBS/DAY)				Cl_2-8.4									
LAND (ACRES)		6		12.9									
LABOR (MAN YRS/YR)		.05-.07		.2									
OUTPUTS - BOD (MG/L)		40		1									
(LBS/DAY)		34		1									
SUSPENDED SOLIDS (MG/L)		64		4.2									
(LBS/DAY)		53		3.5									
NUTRIENTS: P (MG/L)		12		.12									
(LBS/DAY)		10		.1									
N (MG/L)		32		4.8									
(LBS/DAY)		25.6		3.5									
HEAVY METALS (LBS/DAY)		.4-8.3		Negligible					DOES				
ATMOSPHERIC EMISSIONS (LBS/DAY)													
SLUDGES-% SOLIDS									NOT				
TOTAL DRY WT. (LBS/DAY)									APPLY				
SOLID WASTE (CU FT/YR)													
NUISANCE - ODOR													
NOISE				Negligible									
TRAFFIC													
SAFETY (INJURIES/10^6 MAN-HRS)		13		Pathogens last 1 mo									
COSTS - CAPITAL ($ x 10^6)		.047		.039-.057									
RUNNING TOTAL CAPITAL ($ x 10^6)		.047		.086-.104									
LAND ($)		6,000		[illegible]									
RUNNING GRAND TOTAL ($ x 10^6)		.053		.105-.123									
OPERATING (¢/1000 GAL)		[illegible]		[illegible]									
10% AMORTIZED (¢/1000 GAL)		17		[illegible]									
TOTAL OPERATING (¢/1000 GAL)		18.7		[illegible]									
RUNNING TOTAL (¢/1000 GAL)		18.7		[illegible]									

Waste Stabilization - Discharge to Land - 100,000 GPD

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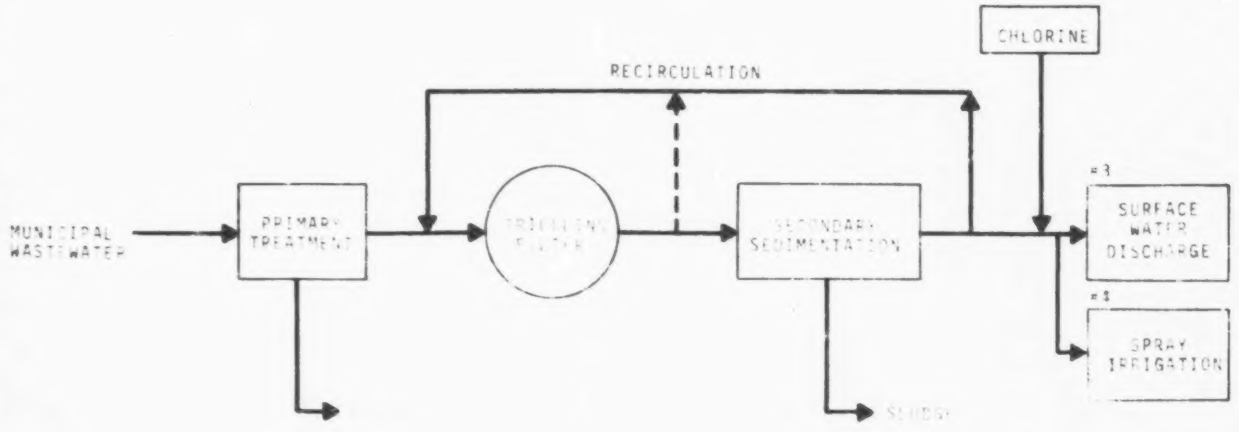
PROCESS PROFILE SHEETS FOR TREATMENT STRATEGY # 3

Trickling Filter with Discharge to Surface Water


MUNICIPAL WASTEWATER
PRIMARY TREATMENT
RECIRCULATION
TRICKLING FILTER
SECONDARY SEDIMENTATION
SLUDGE
CHLORINE
#3
SURFACE WATER DISCHARGE
#1
SPRAY IRRIGATION

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 3 AT A FLOW RATE OF 1 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	1	2	3	4	5	6	7	8
		Trickling Filter		Surface Water	THICKENING:	GRAVITY		GRAVITY	GRAVITY	GRAVITY		GRAVITY	GRAVITY
					CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	250 kwh	450 kwh				57 kwh $6x10^6$ Btu	56 kwh $7x10^6$ Btu	60 kwh $2.8x10^6$ Btu	3 kwh	3 kwh	Not Practical	25 kwh	25 kwh
CONCRETE (CU YDS)	98	153		41		23	24	20	150	150		152	152
STEEL (TONS)	9.6	17.5		2.7		45	41	40	16	16		18	18
CHEMICALS (LBS/DAY)				Chlorine 84		3-17	3.5-7.0					5-18	5-18
LAND (ACRES)		4				.27-.37	.26-.35	.19-.25	.51-.69	4-17		.23-.31	.017-.023
LABOR (MAN YRS/YR)	2.6	.5				1.8-2.4	1.4-1.8	1.1-1.5	.9-1.75	1.1-1.5		1.4-1.8	2.2-3
OUTPUTS - BOD (MG/L)	130	30-50											
(LBS/DAY)	1040	250-417											
SUSPENDED SOLIDS (MG/L)	80	40-60											
(LBS/DAY)	640	337-500											
NUTRIENTS: P (MG/L)	14.3	10											
(LBS/DAY)	114	84				25-40	25-40	25-40	25-40	25-40		25-40	25-40
N (MG/L)	32	24											
(LBS/DAY)	256	201							40-70	40-70		40-70	40-70
HEAVY METALS (LBS/DAY)		3-67		3-67		1-16	1-16	1-16	1-16	1-16		1-16	1-16
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=.07-.1 NO_x=.5-.78	SO_2=.07-.1 Particulates=	HCl=.35-.6 2.2-3.3					
SLUDGES-% SOLIDS	5	7.5				100	100	100	25-50	7.5		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	1080	320				450	450	315	930	930		930	930
SOLID WASTE (CU FT/YR)						1.9-11.2	2.3-4.6					3.3-11.8	3.3-11.8
NUISANCE - ODOR	Potential	Potential				None	None	None	Potential	Potential		Potential	None
NOISE													
TRAFFIC				Negligible		.01	.01	.008	.02	.02		.02	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)		19.6											
COSTS - CAPITAL ($ x 10^6)	.455	.65		.02		.345-.37	.24-.33	.26-.33	.175-.18	.12-.17		.2-.35	.66-.81
RUNNING TOTAL CAPITAL($ x 10^6)	.455	1.1		1.12		1.47-1.49	1.36-1.45	1.38-1.45	1.29-1.3	1.24-1.29		1.32-1.47	1.78-1.93
LAND ($)		4000				270-370	260-350	190-250	510-690	3500-14,000		230-310	17-23
RUNNING GRAND TOTAL ($ x 10^6)	.455	1.11		1.13		1.48-1.59	1.37-1.46	1.39-1.46	1.39-1.31	1.25-1.32		1.33-1.48	1.79-1.94
OPERATING (¢/1000 GAL)	6	2		1.1		4.3-4.9	4.0-5.5	3.5-4.2	1.8-2.5	.91-1.15		1.9-3.5	2.7-4.9
10% AMORTIZED (¢/1000 GAL)	14.6	21.0		.63		11.1-11.9	7.7-10.6	6.4-10.6	5.6-5.8	3.9-5.9		6.4-11.3	21.2-26.1
TOTAL OPERATING (¢/1000 GAL)	20.6	23.0		1.7		15.3-16.8	12.7-16.1	9.9-14.8	7.4-8.3	4.8-7.0		8.3-14.8	23.9-31.[illegible]
RUNNING TOTAL (¢/1000 GAL)	20.6	43.6		45.3		60.6-62.1	57-61.4	55.[illegible]-60.[illegible]	52.7-53.6	50.1-52.3		53.6-60.[illegible]	69.2-76.[illegible]

Trickling Filter - Discharge To Surface Water - 1 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 3 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECON-DARY Trickling Filter	TERTI-ARY	LIQUID DISPOSAL Surface Water	UNIT OPERATION	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY		GRAVITY	GRAVITY	GRAVITY		GRAVITY	GRAVITY
					CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270 kwh	1774 kwh				670 kwh 60×10^6 Btu	560 70×10^6 Btu	600 kwh 28×10^6 Btu	30 kwh	30 kwh	Not Practical	250 kwh	250 kwh
CONCRETE (CU YDS)	756	1160		252		27	26	30	775	775		780	780
STEEL (TONS)	75	108		66.7		48	45	58	78	78		83	83
CHEMICALS (LBS/DAY)				Chlorine 840		30-170	35-70					50-180	50-180
LAND (ACRES)		20				2.7-3.7	2.6-3.6	1.9-2.5	5.4-7.2	40-170		2.2-3	.17-.23
LABOR (MAN YRS/YR)	3.2	3				4.3-5.8	3.6-4.8	4.1-4.5	2.25-11.5	9.6-12.9		2.6-3.5	3.4-4.6
OUTPUTS - BOD (MG/L)	130	30-50											
(LBS/DAY)	10,400	2500-4170											
SUSPENDED SOLIDS (MG/L)	80	40-60											
(LBS/DAY)	6400	3370-5000											
NUTRIENTS: P (MG/L)	14.3	10											
(LBS/DAY)	1140	840				250-400	250-400	250-400	250-400	250-400		250-400	250-400
N (MG/L)	32	24											
(LBS/DAY)	2560	2010							400-700	400-700		400-700	400-700
HEAVY METALS (LBS/DAY)		30-670		30-670		9-159	9-159	9-159	10-160	10-160		10-160	10-160
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=.7-1 NO_x=5-7.8	SO_2=.7-1 Particulates=	HCl=.35-6 22-33					
SLUDGES-% SOLIDS	5	7.5				100	100	100	25-50	7.5		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	10,800	3200				4500	4500	3150	9300	9300		9300	9300
SOLID WASTE (CU FT/YR)						19-112	23-46					33-118	33-118
NUISANCE - ODOR	Poten-tial	Poten-tial				None	None	None	Potential	Potential		Potential	None
NOISE							Above Average						
TRAFFIC				.02		.11	.11	.08	.23	.23		.23	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)		28.5											
COSTS - CAPITAL ($ x 10^6)	2.21	1.6-1.7		.087		.94-1.3	.65-.88	.73-.98	.46-.47	.24-.32		.40-.64	.84-1.1
RUNNING TOTAL CAPITAL($ x 10^6)	2.21	3.81-3.91		3.9-4.0		4.84-5.3	4.55-4.88	4.63-4.98	4.36-4.47	4.14-4.32		4.3-4.64	4.74-5.1
LAND ($)		20,000				2700-3700	2600-3600	2600-3600	5400-7200	.4-1.7x10^5		2200-3000	170-230
RUNNING GRAND TOTAL ($ x 10^6)	2.21	3.83-3.93		3.92-4.02		4.86-5.32	4.57-4.90	4.65-5.0	4.39-4.5	4.2-4.51		4.32-4.66	4.76-5.12
OPERATING (¢/1000 GAL)	4	2		.9		3.2-3.8	2.9-4.3	2.4-3.2	1.7-2.3	.91-1.15		1.6-3.3	1.2-3
10% AMORTIZED (¢/1000 GAL)	7.1	5.2-5.5		.3		3.0-4.2	2.1-2.8	2.3-3.2	1.5	.9-1.6		1.3-2.0	2.7-3.5
TOTAL OPERATING (¢/1000 GAL)	11.1	7.2-7.5		1.2		6.2-8.0	5.0-7.1	4.7-6.4	3.2-3.8	1.8-2.8		2.9-5.3	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	11.1	18.3-18.6		19.5-19.8		25.7-27.8	24.5-26.9	24.2-26.2	22.7-23.6	21.3-22.6		22.4-25.1	23.4-26.3

Trickling Filter - Discharge to Surface Water - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 3 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY		GRAVITY	GRAVITY	GRAVITY	GRAVITY	GRAVITY	GRAVITY
					CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
		Trickling Filter		Surface Water	DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	4000 kwh	4790 kwh				6700 kwh 600x10^6 Btu	5600 kwh 700x10^6 Btu	6000 kwh 280x10^6 Btu	300 kwh	300 kwh	300 kwh	2500 kwh	2500 kwh
CONCRETE (CU YDS)	6240	10,900		2120		165	142	172	890	890	890	915	915
STEEL (TONS)	545	882		140		220	200	236	82	80	80	100	100
CHEMICALS (LBS/DAY)				Chlorine 8400		300-1700	350-700					500-1800	500-1800
LAND (ACRES)		40				26.7-36.1	26-36	19-25	54-72	401-1701	1.7-2.3	22-30	1.8-2.4
LABOR (MAN YRS/YR)	28	24.5				22-28	23-31	19-24	12.5-39	7.8-10.6	7.8-10.6	15-21	15-22
OUTPUTS - BOD (MG/L)	130	30-50											
(LBS/DAY)	104,000	25-4x10^4											
SUSPENDED SOLIDS (MG/L)	80	40-60											
(LBS/DAY)	64,000	3-5x10^4											
NUTRIENTS: P (MG/L)	14.3	10											
(LBS/DAY)	11,400	8400				2500-4000	2500-4000	2500-4000	2500-4000	2500-4000	2500-4000	2500-4000	2500-4000
N (MG/L)	32	24											
(LBS/DAY)	25,600	20,100							4000-7000	4000-7000	4000-7000	4000-7000	4000-7000
HEAVY METALS (LBS/DAY)		300-6700		300-6700		93-1590	93-1590	93-1590	100-1600	100-1600	100-1600	100-1600	100-1600
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=7-10	SO_2=7-10 NO_x=50-78	HCl=35-60 Particulates=220-330					
SLUDGES-% SOLIDS	5	7.5				100	100	100	25-50	7.5	7.5	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	108,000	32,000				45,000	45,000	31,500	93,000	93,000	93,000	93,000	93,000
SOLID WASTE (CU FT/YR)						197-1117	230-460					329-1183	329-1183
NUISANCE - ODOR	Potential	Potential				None	None	None	Potential	Potential	None	Potential	None
NOISE							Above Average						
TRAFFIC				.2		1.1	1.1	.79	2.3	2.3	None	2.3	.25
SAFETY (INJURIES/10^6 MAN-HRS)		41											
COSTS - CAPITAL ($ x 10^6)	11.7	12.35		.416		3.2-4.4	2.2-3	4-5.4	3.1-3.3	3.3-3.7	14.5-19.7	2.4-3.2	3.15-3.2
RUNNING TOTAL CAPITAL ($ x 10^6)	11.7	24.1		24.5		27.7-28.9	26.7-27.5	28.5-29.9	27.6-27.8	27.8-28.2	39-44.2	26.9-27.7	27.6-27.7
LAND ($)		40,000				26,700-36,100	26,000-36,000	19,000-25,000	54,000-72,000	.4-1.7x10^6	1700-2300	22,000-30,000	1800-2400
RUNNING GRAND TOTAL ($ x 10^6)	11.7	24.1		24.5		27.8-30	26.8-27.6	28.6-30	27.7-27.9	28.2-29.9	39-44.2	27-27.8	27.6-27.7
OPERATING (¢/1000 GAL)	2.6	1.7		.7		2.7-3.3	2.7-4.1	2.2-2.9	1.7-2.3	.98-1.2	.4-.5	1.5-3.2	1.2-3
10% AMORTIZED (¢/1000 GAL)	3.8	4.0		.1		1.0-1.4	.7-1.0	1.3-1.7	1.0-1.1	1.2-1.3	4.7-6.3	.8-1.0	1.0
TOTAL OPERATING (¢/1000 GAL)	6.4	5.7		.8		3.7-4.7	3.4-5.1	3.5-4.6	2.7-3.4	2.2-2.5	5.1-6.8	2.3-4.2	2.2-4.0
RUNNING TOTAL (¢/1000 GAL)	6.4	12.1		12.9		16.6-17.6	16.3-18	16.4-17.5	15.6-16.3	15.1-15.4	18-19.7	15.2-17.1	15.1-16.9

Trickling Filter - Discharge to Surface Water - 100 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 3 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTION							
	PRIMARY	SECONDARY Trickling Filter	TERTIARY	LIQUID DISPOSAL Surface Water	UNIT OPERATION THICKENING CONDITIONING DEWATERING DISPOSAL	1 GRAVITY CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 GRAVITY PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 GRAVITY DIGESTION SAND DRYING LANDFILL	5 GRAVITY DIGESTION LAND SPREADING	6 GRAVITY DIGESTION OCEAN DUMPING	7 GRAVITY DIGESTION VACUUM FILTRATION LANDFILL	8 GRAVITY DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	40,000 kwh	47,900 kwh				67,000 kwh 6x10^9 Btu	56,000 kwh 7x10^9 Btu	73,000 kwh 2.8x10^7 Btu	3000 kwh	3000 kwh	3000 kwh	25,000 kwh	25,000 kwh
CONCRETE (CU YDS)	61,600	109,000		19,300		1430	1280	1460	8500	8500	8500	8670	8670
STEEL (TONS)	5400	8820		1270		1730	1610	1850	780	780	780	920	920
CHEMICALS (LBS/DAY)				Chlorine 84,000		3000-17,000	3500-7000					5000-18,000	5000-18,000
LAND (ACRES)		200				267-361	260-360	190-250	540-720	4000-17,000	15.3-20.7	220-300	18-24
LABOR (MAN YRS/YR)	280	245				220-280	230-310	190-240	125-390	72-98	70.6-95.5	150-210	150-220
OUTPUTS - BOD (MG/L)	130	30-50											
(LBS/DAY)	1.04x10^6	2.5-4x10^5											
SUSPENDED SOLIDS (MG/L)	80	40-60											
(LBS/DAY)	640,000	3-5x10^5											
NUTRIENTS: P (MG/L)	14.3	10											
(LBS/DAY)	114,000	84,000				2.5-4x10^4	2.5-4x10^4	2.5-4x10^4	2.5-4x10^4	2.5-4x10^4	2.5-4x10^4	2.5-4x10^4	2.5-4x10^4
N (MG/L)	32	24											
(LBS/DAY)	256,000	201,000							4-7x10^4	4-7x10^4	4-7x10^4	4-7x10^4	4-7x10^4
HEAVY METALS (LBS/DAY)		3000-67,000		3000-67,000		930-15,900	930-15,900	930-15,900	1000-16,000	1000-16,000	1000-16,000	1000-16,000	1000-16,000
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=70-100 NO$_x$=500-780,	SO$_2$=70-100 Particulates =	HCl=350-600 2200-3300					
SLUDGES-% SOLIDS	5	7.5				100	100	100	25-50	7.5	7.5	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	1.08x10^6	320,000				450,000	450,000	315,000	930,000	930,000	930,000	930,000	930,000
SOLID WASTE (CU FT/YR)						1970-11,170	2300-4600					3290-11,830	3290-11,830
NUISANCE ODOR	Potential	Potential				None	None	None	Potential	Potential	None	Potential	None
NOISE							Above Average						
TRAFFIC				2.1		11.2	11.7	7.87	23.3	23.3	None	23.8	0.5
SAFETY (INJURIES/10^6 MAN-HRS)		41											
COSTS - CAPITAL ($ x 10^6)	117	117		2.16		32-44	22-30	40-54	32-34	8-14	15-21	24-32	31.5-32
RUNNING TOTAL CAPITAL ($ x 10^6)	117	234		236.2		268.2-280.2	258.2-266.2	276.2-290.2	268.2-270.2	244.2-250.2	251.2-257.2	260.2-268.2	267.7-268.2
LAND ($)		.2x10^6				.27-.36x10^6	.26-.36x10^6	.19-.25x10^6	.54-.72x10^6	4-17x10^6	15,300-20,700	.22-.3x10^6	18,000-24,000
RUNNING GRAND TOTAL ($ x 10^6)	117	234.2		236.4		268.7-280.8	258.7-266.8	276.6-290.6	268.9-271.1	248.4-267.4	251.4-257.4	260.6-268.7	267.9-268.4
OPERATING (¢/1000 GAL)	2	1.3		.5		2.7-3.3	2.7-4.1	2.2-2.9	1.7-2.3	4.5-6.9	.14-.19	1.5-3.2	1.2-3
10% AMORTIZED (¢/1000 GAL)	3.8	3.8		.07		1.0-1.4	.7-1.0	1.3-1.7	1.0-1.1	.3-.5	.5-.7	.8-1.0	1.0
TOTAL OPERATING (¢/1000 GAL)	5.8	5.1		.57		3.7-4.7	3.4-5.1	3.5-4.6	2.7-3.4	4.8-7.4	.64-.89	2.3-4.2	2.2-4.0
RUNNING TOTAL (¢/1000 GAL)	5.8	10.9		11.5		15.2-16.2	14.9-16.6	15.0-16.1	14.2-14.9	16.3-18.9	12.1-12.4	13.8-15.7	13.7-15.5

Trickling Filter - Discharge to Surface Water - 1000 MGD

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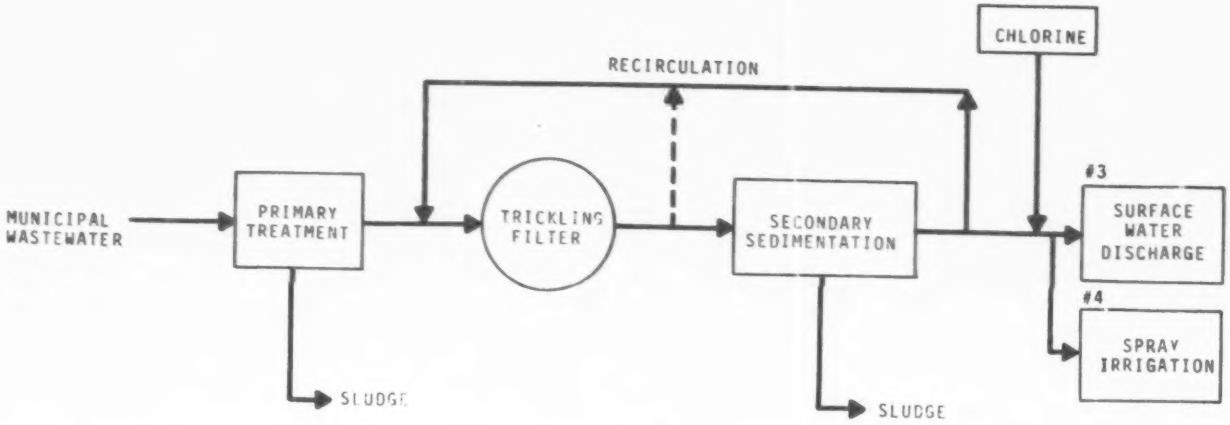
PROCESS PROFILE SHEETS FOR TREATMENT STRATEGY # 4

Trickling Filter with Discharge of Liquid Effluent to Land


CHLORINE
RECIRCULATION
MUNICIPAL WASTEWATER
PRIMARY TREATMENT
TRICKLING FILTER
SECONDARY SEDIMENTATION
#3
SURFACE WATER DISCHARGE
#4
SPRAY IRRIGATION
SLUDGE
SLUDGE

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 4 AT A FLOW RATE OF 1 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECON-DARY Trickling Filter	TERTI-ARY	LIQUID DISPOSAL Land	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	1 GRAVITY CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 GRAVITY PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 GRAVITY DIGESTION SAND DRYING LANDFILL	5 GRAVITY DIGESTION LAND SPREADING	6 DIGESTION OCEAN DUMPING	7 GRAVITY DIGESTION VACUUM FILTRATION LANDFILL	8 GRAVITY DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	250 kwh	400 kwh		800 kwh		57 kwh 6x10^6 Btu	56 kwh 2x10^6 Btu	60 kwh 2.8x10^6 Btu	3 kwh	3 kwh	Not Practical	25 kwh	25 kwh
CONCRETE (CU YDS)	98	153		41		23	24	20	150	150		152	152
STEEL (TONS)	9.6	17.5		22.7		45	41	40	16	16		18	18
CHEMICALS (LBS/DAY)				Chlorine 84		3-17	3.5-7.0					5-18	5-18
LAND (ACRES)		4		129		.27-.37	.26-.35	.19-.25	.51-.69	4-17		.23-.31	.017-.023
LABOR (MAN YRS/YR)	2.6	.5		1		1.8-2.4	1.4-1.8	1.1-1.5	.9-1.75	1.1-1.5		1.4-1.8	2.2-3
OUTPUTS - BOD (MG/L)	130	30-50		.6-1.0									
(LBS/DAY)	1040	250-417		5-8.3									
SUSPENDED SOLIDS (MG/L)	80	40-60		1.4-4									
(LBS/DAY)	640	337-500		2.1-5.2									
NUTRIENTS: P (MG/L)	14.3	10		.1									
(LBS/DAY)	114	84		.8		25-40	25-40	25-40	25-40	25-40		25-40	25-40
N (MG/L)	32	24		3.6									
(LBS/DAY)	256	201		30.2					40-70	40-70		40-70	40-70
HEAVY METALS (LBS/DAY)		3-67		.2-3.2		1-16	1-16	1-16	1-16	1-16		1-16	1-16
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=.07-.1 NO$_x$=.50-.78	SO$_2$=.07-.1 Particulates=2.2-3.3	HCl=.35-.6					
SLUDGES-% SOLIDS	5	7.5				100	100	100	25-50	7.5		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	1080	320				450	450	315	930	930		930	930
SOLID WASTE (CU FT/YR)						1.9-11.2	2.3-4.6					3.3-11.8	3.3-11.8
NUISANCE - ODOR	Potential	Potential				None	None	None	Potential	Potential		Potential	None
NOISE													
TRAFFIC				Negligible		.01	.01	.008	.02	.02		.02	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)		19.6		Pathogens Last 1 mo									
COSTS - CAPITAL ($ x 10^6)	.455	.65		.39-.57		.345-.37	.24-.33	.26-.32	.175-.18	.12-.17		.2-.35	.66-.81
RUNNING TOTAL CAPITAL ($ x 10^6)	.455	1.1		1.5-1.7		1.85-2.07	1.74-2.03	1.76-2.02	1.67-1.88	.162-.187		.17-.205	.216-.251
LAND ($)		4000		129,000		270-370	260-350	192-250	510-690	3500-14,000		230-310	17-23
RUNNING GRAND TOTAL ($ x 10^6)	.455	1.11		1.63-1.8		1.98-2.18	1.87-2.14	1.89-2.13	1.81-1.99	1.75-1.99		1.83-2.16	2.29-2.62
OPERATING (¢/1000 GAL)	6	2		5 -9		4.3-4.9	4.0-5.5	3.5-4.2	1.8-2.5	.91-1.15		1.9-3.5	2.7-4.9
10% AMORTIZED (¢/1000 GAL)	14.6	21.0		16.7-22.		11.1-11.9	7.7-10.6	6.4-10.6	5.6-5.8	3.9-5.9		6.4-11.3	21.2-26.1
TOTAL OPERATING (¢/1000 GAL)	20.6	23.0		21.7-31.		15.4-16.8	11.7-16.1	9.9-14.8	7.4-8.3	4.8-7.1		8.3-14.8	23.9-31.0
RUNNING TOTAL (¢/1000 GAL)	20.6	43.6		65.3-75.1		80.7-91.9	77-91.2	75.2-89.9	72.7-83.4	70.1-82.2		73.6-89.9	89.2-106.1

Trickling Filter - Discharge to Land - 1 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 4 AT A FLOW RATE OF 10 MGD

		LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
		PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	1	2	3	4	5	6	7	8
						THICKENING:	GRAVITY		GRAVITY	GRAVITY	GRAVITY		GRAVITY	GRAVITY
						CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
						DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
			Trickling Filter		Land	DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS -	ENERGY (UNITS/DAY)	1270 kwh	1774 kwh		4600 kwh		670 kwh 60x10^6 Btu	560 kwh 70x10^6 Btu	600 kwh 29x10^6 Btu	30 kwh	30 kwh	Not Practical	250 kwh	250 kwh
	CONCRETE (CU YDS)	756	1160		252		27	26	30	775	775		780	780
	STEEL (TONS)	75	108		66.7		48	45	58	79	78		83	83
	CHEMICALS (LBS/DAY)				Chlorine 840		30-170	35-70					50-180	50-180
	LAND (ACRES)		20		1290		2.7-3.7	2.6-3.6	1.9-2.5	5.4-7.2	40-170		2.2-3	.17-.23
	LABOR (MAN YRS/YR)	3.2	3		10		4.3-5.8	3.6-4.8	4.1-4.5	2.25-11.5	9.6-12.9		2.6-3.5	3.4-4.6
OUTPUTS -	BOD (MG/L)	130	30-50		.6-1.0									
	(LBS/DAY)	10,400	2500-4170		50-83									
	SUSPENDED SOLIDS (MG/L)	80	40-60		1.4-4									
	(LBS/DAY)	6400	3370-5000		21-52									
	NUTRIENTS: P (MG/L)	14.3	10		.1									
	(LBS/DAY)	1140	840		8		250-400	250-400	250-400	250-400	250-400		250-400	250-400
	N (MG/L)	32	24		3.6									
	(LBS/DAY)	2560	2010		302					400-700	400-700		400-700	400-700
	HEAVY METALS (LBS/DAY)		30-630		2-32		9-159	9-159	9-159	10-160	10-160		10-160	10-160
	ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=.7-1 NO$_x$=5.0-7.8	SO$_2$=.7-1 Particulates =	HCl=3.5-6 22-33					
	SLUDGES-% SOLIDS	5	7.5				100	100	100	25-50	7.5		20-30	20-30
	TOTAL DRY WT. (LBS/DAY)	10,800	3200				4500	4500	3150	9300	9300		9300	9300
	SOLID WASTE (CU FT/YR)						19-112	23-46					33-118	33-118
	NUISANCE - ODOR	Potential	Potential				None	None	None	Potential	Potential		Potential	None
	NOISE							Above Average						
	TRAFFIC				.02		.11	.11	.08	.23	.21		.23	Negligible
	SAFETY (INJURIES/10^6 MAN-HRS)		28.5		Pathogens Last 1 mo									
COSTS -	CAPITAL ($ x 10^6)	2.21	1.6-1.7		3.9-5.7		.94-1.3	.65-.88	.73-.98	.46-.47	.24-.32		.40-.64	.84-1.1
	RUNNING TOTAL CAPITAL ($ x 10^6)	2.21	3.81-3.91		7.71-9.61		8.65-10.9	8.36-10.5	8.44-10.6	8.17-10.1	7.95-9.93		8.11-10.2	8.55-10.7
	LAND ($)		20,000		1.29x10^6		2700-3700	2600-3600	1900-2500	5400-7200	.4-1.7x10^5		2200-3000	170-230
	RUNNING GRAND TOTAL ($ x 10^6)	2.21	3.83-3.93		9.02-10.9		9.96-12.2	9.67-11.8	9.75-11.9	9.49-11.4	9.3-11.4		9.42-11.5	9.86-12.0
	OPERATING (¢/1000 GAL)	4	2		5 —9		3.2-3.8	2.9-4.3	2.4-3.2	1.7-2.3	.91-1.15		1.6-3.3	1.2-3
	10% AMORTIZED (¢/1000 GAL)	7.1	5.2-5.5		16.7-22.5		3.0-4.2	2.1-2.8	2.3-3.2	1.5	.9-1.6		1.3-2.0	2.7-3.5
	TOTAL OPERATING (¢/1000 GAL)	11.1	7.2-7.5		21.7-31.5		6.2-8.0	5.0-7.1	4.7-6.4	3.2-3.8	1.8-2.8		2.9-5.3	3.9-6.5
	RUNNING TOTAL (¢/1000 GAL)	11.1	18.3-18.6		40.0-50.1		46.2-58.1	45.0-57.2	44.7-56.5	43.2-53.9	41.8-52.9		42.9-55.4	43.9-56.6

Trickling Filter - Discharge to Land - 10 MGD

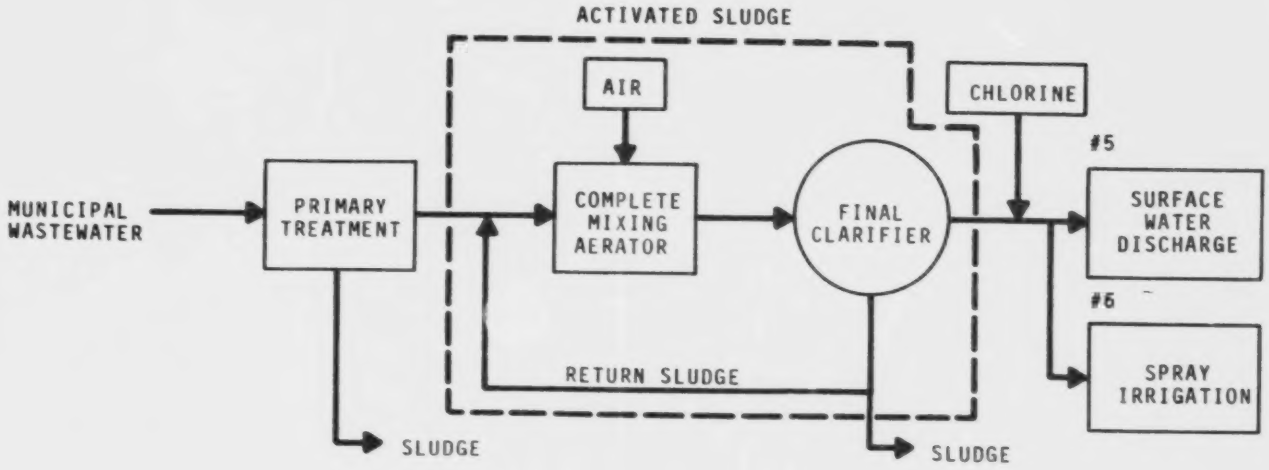
PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 4 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Trickling Filter	TERTIARY	LIQUID DISPOSAL Land	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	1 GRAVITY CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 GRAVITY PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 GRAVITY DIGESTION SAND DRYING LANDFILL	5 GRAVITY DIGESTION LAND SPREADING	6 GRAVITY DIGESTION OCEAN DUMPING	7 GRAVITY DIGESTION VACUUM FILTRATION LANDFILL	8 GRAVITY DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	4000 kwh	4790 kwh		18,800 kwh		6700 kwh 600x10^6 Btu	5600 kwh 790x10^6 Btu	6000 kwh 280x10^6 Btu	300 kwh	300 kwh	300 kwh	2500 kwh	2500 kwh
CONCRETE (CU YDS)	6240	10,900		1000		165	142	122	890	890	890	915	915
STEEL (TONS)	545	882		265		220	200	236	82	80	80	100	100
CHEMICALS (LBS/DAY)				Cl_2-8400		300-1700	350-700					500-1800	500-1800
LAND (ACRES)		40		12,900		26.7-36.1	26-36	19-25	54-72	401-1701	1.7-2.3	22-30	1.8-2.4
LABOR (MAN YRS/YR)	28	24.5		55		22-28	23-31	19-24	12.5-39	7.8-10.6	7.8-10.6	15-21	15-22
OUTPUTS - BOD (MG/L)	130	30-50		.6-1.0									
(LBS/DAY)	104,000	2-4x10^4		500-830									
SUSPENDED SOLIDS (MG/L)	80	40-60		1.4-4									
(LBS/DAY)	64,000	3-5x10^4		210-520									
NUTRIENTS: P (MG/L)	14.3	10		0.1									
(LBS/DAY)	11,400	8400		83		2500-4000	2500-4000	2500-4000	2500-4000	2500-4000	2500-4000	2500-4000	2500-4000
N (MG/L)	32	24		2.9-3.6									
(LBS/DAY)	25,600	20,100		2000-3020					4000-7000	4000-7000	4000-7000	4000-7000	4000-7000
HEAVY METALS (LBS/DAY)		300-6700		20-120		93-1590	93-1590	93-1590	100-1600	100-1600	100-1600	100-1600	100-1600
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=7-10 NO_x=50-78	SO_2=7-10 Particulates =	HCl=35-60 220-330					
SLUDGES-% SOLIDS	5	7.5				100	100	100	25-50	7.5	7.5	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	108,000	32,000				45,000	45,000	31,500	93,000	93,000	93,000	93,000	93,000
SOLID WASTE (CU FT/YR)						197-1117	230-460					329-1183	329-1183
NUISANCE - ODOR	Potential	Potential				None	None	None	Potential	Potential	None	Potential	None
NOISE							Above Average						
TRAFFIC				.2									
SAFETY (INJURIES/10^6 MAN-HRS)		41		Pathogens Last 1 month		1.1	1.1	.79	2.3	2.3	None	2.3	.25
COSTS - CAPITAL ($ x 10^6)	11.7	12.35		39-57		3.2-4.4	2.2-3	4-5.4	3.1-3.3	3.3-3.7	14.5-19.7	2.4-3.2	3.15-3.2
RUNNING TOTAL CAPITAL ($ x 10^6)	11.7	24.1		63.1-81.1		66.3-85.5	65.3-84.1	67.1-86.5	66.2-84.4	66.4-84.8	77.6-100.8	65.3-84.3	66.3-84.3
LAND ($)		40,000		12.9x10^6		26,700-36,100	26,000-36,000	19,000-25,000	54,000-72,000	4-1.7x10^6	1700-2300	22,000-30,000	1800-2400
RUNNING GRAND TOTAL ($ x 10^6)	11.7	24.1		76-94		79.2-98.4	79.2-97	80-99.4	79.2-97.4	79.7-99.4	90.5-113.7	78.4-97.2	79.2-97.2
OPERATING (¢/1000 GAL)	2.6	1.7		5-9		2.7-3.3	2.7-4.1	2.2-2.9	1.7-2.3	.98-1.2	.4-.5	1.5-3.2	1.2-3
10% AMORTIZED (¢/1000 GAL)	3.8	4.0		16.7-22.5		1.0-1.4	.7-1.0	1.3-1.7	1.0-1.1	1.2-1.3	4.7-6.3	.8-1.0	1.0
TOTAL OPERATING (¢/1000 GAL)	6.4	5.7		21.7-31.5		3.7-4.7	3.4-5.1	3.5-4.6	2.7-3.4	2.2-2.5	5.1-6.8	2.3-4.2	2.2-4.0
RUNNING TOTAL (¢/1000 GAL)	6.4	12.1		33.8-43.6		37.5-48.3	37.2-48.7	37.3-48.2	36.5-47	36-46.1	38.9-50.4	36.1-47.8	36-47.6

Trickling Filter - Discharge to Land - 100 MGD

PROCESS PROFILE SHEETS FOR TREATMENT STRATEGY # 5

Activated Sludge with Discharge to Surface Waters


ACTIVATED SLUDGE
AIR
CHLORINE
#5
MUNICIPAL WASTEWATER
PRIMARY TREATMENT
COMPLETE MIXING AERATOR
FINAL CLARIFIER
SURFACE WATER DISCHARGE
#6
RETURN SLUDGE
SPRAY IRRIGATION
SLUDGE
SLUDGE

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 5 AT A FLOW RATE OF 1 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	1	2	3	4	5	6	7	8
		Activated Sludge		Surface Water	THICKENING:	FLOTATION		FLOTATION	FLOTATION	FLOTATION		FLOTATION	FLOTATION
					CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	250 kwh	933 kwh				181 kwh 10×10^6 Btu	151 kwh 12×10^6 Btu	146 kwh 4.7×10^6 Btu	22 kwh	22 kwh	Not Practical	126 kwh	126 kwh
CONCRETE (CU YDS)	98	175		41		22	19	20	360	360		362	362
STEEL (TONS)	9.6	25		2.7		50	50	40	36	36		38	58
CHEMICALS (LBS/DAY)				Chlorine 67		19-27	4.5-5.5	1.2-5.8	1.2-5.8	1.2-5.8		13.2-18.8	13.2-18.8
LAND (ACRES)		3.8				.43-.58	.41-.55	.255-.345	1.4-1.6	6-26		.86-1.2	.034-.05
LABOR (MAN YRS/YR)	2.6	1.0				2.2-2.6	1.7-2.1	2.0-2.4	1.2-2.1	1.4-1.9		1.6-2.2	2.6-3.5
OUTPUTS - BOD (MG/L)	130	10-30											
(LBS/DAY)	1040	83-250											
SUSPENDED SOLIDS (MG/L)	80	10-30											
(LBS/DAY)	640	35-250											
NUTRIENTS: P (MG/L)	14.3	10											
(LBS/DAY)	114	84				50-70	50-70	50-70	50-70	50-70		50-70	50-70
N (MG/L)	32	25											
(LBS/DAY)	256	210							80-100	80-100		80-100	80-100
HEAVY METALS (LBS/DAY)		2.5-50		2.5-50		1.3-33	1.3-33	1.3-33	1.5-33	1.5-33		1.5-33	1.5-33
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=.25-.4 NO_x =	SO_2=.44-.67 2.5-3.9	HCl=.08-.12 Particulates=4.4-7					
SLUDGES-% SOLIDS	5	1				100	100	100	25-50	6-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	1080	1250				699	699	524	1400	1400		1400	1400
SOLID WASTE (CU FT/YR)						12-18	3-3.6	.8-3.8	.8-3.8	.8-3.8		9-12	9-12
NUISANCE - ODOR	Potential	Potential				None	None	None	Potential	Potential		Potential	None
NOISE													
TRAFFIC				Negligible		.02	.02	.01	.035	.035		.035	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)		19.6											
COSTS - CAPITAL ($ x 10^6)	.455	.26-.3		.019		.37-.445	.37-.51	.46-.465	.25-.26	.19-.25		.28-.3	.67-.7
RUNNING TOTAL CAPITAL ($ x 10^6)	.455	.715-.755		.734-.774		1.1-1.2	1.1-1.28	1.19-1.24	.98-1.03	.92-1.02		1.0-1.07	1.41-1.47
LAND ($)		3800				430-580	410-550	255-345	1400-1600	6000-26,000		860-1200	34-50
RUNNING GRAND TOTAL ($ x 10^6)	.455	.719-.759		.738-.778		1.11-1.22	1.11-1.29	1.2-1.24	.99-1.04	.93-1.05		1.02-1.08	1.41-1.48
OPERATING (¢/1000 GAL)	6	5.1		1.1		5.6-8.1	4.2-5.9	4.9-6.4	3.1-4.1	2.6-2.9		3.0-5.0	4.4-6.7
10% AMORTIZED (¢/1000 GAL)	14.6	8.5-9.8		.6		11.9-14.3	11.9-16.4	14.8-15.0	8.0-8.4	6.3-8.9		9.0-9.6	21.9-22.5
TOTAL OPERATING (¢/1000 GAL)	20.6	13.6-14.9		1.7		17.5-22.4	16.1-22.3	19.7-21.4	11.1-12.5	8.9-11.8		12.0-14.6	26.3-29.2
RUNNING TOTAL (¢/1000 GAL)	20.6	34.2-35.5		35.9-37.2		53.4-59.6	52-59.5	55.6-58.6	47-49.7	44.8-49		47.9-51.8	62.2-66.4

Activated Sludge - Discharge to Surface Waters - 1 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 5 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	1	2	3	4	5	6	7	8
					THICKENING:	FLOTATION		FLOTATION	FLOTATION	FLOTATION		FLOTATION	FLOTATION
					CONDITIONING:	CHEMICAL	CHEMICAL	CHEMICAL	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
		Activated Sludge		Surface Water	DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270 kwh	3734 kwh				1810 kwh 100x10⁶ Btu	1510 kwh 120x10⁶ Btu	1660 kwh 47x10⁶ Btu	220 kwh	220 kwh	Not Practical	1260kwh	1260kwh
CONCRETE (CU YDS)	756	2100		252		30	28	34	1210	1210		1220	1220
STEEL (TONS)	75	290		66.7		55	56	70	120	120		125	125
CHEMICALS (LBS/DAY)				Chlorine 670		192-268	45-55	11-58	11-58	12-58		132-188	132-188
LAND (ACRES)		19				4.3-5.8	4.1-5.5	2.7-3.7	13.7-15.4	60-260		8.2-11.2	.34-.5
LABOR (MAN YRS/YR)	3.2	7.9				5.6-7.5	4.1-5.8	4.3-6.3	3.4-7.9	10.2-13.9		4.1-4.8	4.8-5.5
OUTPUTS - BOD (MG/L)	130	10-30											
(LBS/DAY)	10,400	830-2500											
SUSPENDED SOLIDS (MG/L)	80	10-30											
(LBS/DAY)	6400	830-2500											
NUTRIENTS: P (MG/L)	14.3	10											
(LBS/DAY)	1140	840				500-700	500-700	500-700	500-700	500-700		500-700	500-700
N (MG/L)	32	25											
(LBS/DAY)	2560	2100							800-1000	800-1000		800-1000	800-1000
HEAVY METALS (LBS/DAY)		25-500		25-500		13-326	13-326	13-326	15-330	15-330		15-330	15-330
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=2.5-4 NO_x=25-39	SO_2=4.4-6.7 Particulates=44-70	HCl=.8-1.2					
SLUDGES-% SOLIDS	5	1				100	100	100	25-50	6-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	10,800	12,500				6990	6990	5240	14,000	14,000		14,000	14,000
SOLID WASTE (CU FT/YR)						120-180	30-36	7-38	7-38	8-38		90-120	98-120
NUISANCE - ODOR	Potential	Potential				None	None	None	Potential	Potential		Potential	None
NOISE							Above Average						
TRAFFIC				.02		.18	.18	.13	.35	.35		.35	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)		28.5											
COSTS - CAPITAL ($ x 10^6)	2.21	1.9-2		.087		1-1.3	1.2-1.3	1.8-2.1	.57-.64	.30-.40		.69-.85	1.1-1.3
RUNNING TOTAL CAPITAL ($ x 10^6)	2.21	4.11-4.21		4.2-4.3		5.2-5.6	5.4-5.6	6.0-6.4	4.77-4.94	4.5-4.7		4.89-5.15	5.3-5.6
LAND ($)		19,000				4300-5800	4100-5500	2700-3700	13,700-15,400	.6-2.6x10^5		8200-11,200	340-500
RUNNING GRAND TOTAL ($ x 10^6)	2.21	4.13-4.23		4.22-4.32		5.22-5.63	5.42-5.63	6.02-6.42	4.8-4.97	4.58-4.98		4.92-5.18	5.32-5.62
OPERATING (¢/1000 GAL)	4	3.4		.9		4.6-7.0	3.15-4.85	3.8-5.3	3.1-4.1	2.6-2.9		3.2-5.4	3.0-5.2
10% AMORTIZED (¢/1000 GAL)	7.1	6.1-6.4		.3		3.2-4.2	3.9-4.2	5.8-6.8	1.8-2.1	1.1-2.1		2.2-2.7	3.5-4.2
TOTAL OPERATING (¢/1000 GAL)	11.1	9.5-9.9		1.2		7.8-11.2	7.1-9.1	9.6-12.1	4.9-6.2	3.7-5.0		5.4-8.1	6.5-9.4
RUNNING TOTAL (¢/1000 GAL)	11.1	20.6-20.9		21.9-22.1		29.6-33.3	28.9-31.2	31.4-34.2	26.7-28.3	25.5-27.1		27.2-30.2	28.3-31.5

Activated Sludge - Discharge to Surface Waters - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 5 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY	LIQUID DISPOSAL Surface Water	UNIT OPERATION	1	2	3	4	5	6	7	8
					THICKENING:	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
					CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	4000 kwh	11,900 kwh				18,100 kwh $1x10^9$ Btu	15,100 kwh $1.2x10^9$ Btu	14,600 kwh $470x10^6$ Btu	2200 kwh	2200 kwh	2200 kwh	12,600 kwh	12,600 kwh
CONCRETE (CU YDS)	6240	14,000		2120		365	342	373	10,200	10,200	10,200	10,200	10,200
STEEL (TONS)	545	1600		140		300	295	340	940	940	940	980	980
CHEMICALS (LBS/DAY)				Chlorine 6700		1917-2683	450-550	117-583	117-583	117-583	117-583	1317-1880	1317-1880
LAND (ACRES)		38				41-55	41-55	27-37	137-154	603-2603	2.6-3.6	82-112	3-4
LABOR (MAN YRS/YR)	28	41				38.4-49.2	26.7-35.4	31-36	20-60	13.6-18.4	13.6-18.4	25-29	25-28
OUTPUTS - BOD (MG/L)	130	10-30											
(LBS/DAY)	$1.04x10^5$	$.8-3x10^4$											
SUSPENDED SOLIDS (MG/L)	80	10-30											
(LBS/DAY)	64,000	$.8-3x10^4$											
NUTRIENTS: P (MG/L)	14.3	10											
(LBS/DAY)	11,400	8400				5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000
N (MG/L)	32	25											
(LBS/DAY)	25,600	21,000							8000-10,000	8000-10,000	8000-10,000	8000-10,000	000-10,000
HEAVY METALS (LBS/DAY)		250-5000		250-5000		125-3260	125-3260	125-3260	150-3300	150-3300	150-3300	150-3300	150-3300
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=25-40 NO_x=250-390	SO_2=44-67 Particulates=	HCl=8-12 440-700					
SLUDGES-% SOLIDS	5	1				100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	108,000	125,000				69,900	69,900	52,400	140,000	140,000	140,000	140,000	140,000
SOLID WASTE (CU FT/YR)						1200-1800	300-360	80-380	80-380	80-380		900-1200	900-1200
NUISANCE - ODOR	Potential	Potential				None	None	None	Potential	Potential	None	Potential	None
NOISE							Above Average						
TRAFFIC				.17		1.75	1.75	1.3	3.5	3.5	.03	3.5	.1
SAFETY (INJURIES/10^6 MAN-HRS)		41											
COSTS - CAPITAL ($ x 10^6)	11.7	14-15		.42		3.4-4.7	5-6.8	11-15	4.4-5.2	5.1-6.9	14.7-19.9	3.7-4.9	3.5-4.7
RUNNING TOTAL CAPITAL ($ x 10^6)	11.7	25.7-26.7		26.1-27.1		29.5-31.8	31.1-33.9	37.1-42.1	30.5-32.2	31.2-34.0	40.8-47	29.8-32	29.6-31.8
LAND ($)		38,000				41,000-55,000	41,000-55,000	27,000-37,000	$1.37-1.54x10^5$	$.6-2.6x10^6$	2600-3600	$.82-1.1x10^5$	3000-4000
RUNNING GRAND TOTAL ($ x 10^6)	11.7	25.7-26.7		26.1-27.1		29.5-31.8	31.1-33.9	37.1-42.1	30.6-32.4	31.8-36.6	40.8-47	29.9-32.1	29.6-31.8
OPERATING (¢/1000 GAL)	2.6	1.2		.7		4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	2.2-2.8	.54-.73	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.8	4.5-4.8		.1		1.1-1.5	1.6-2.2	3.6-4.8	1.4-1.7	1.8-3.1	4.7-6.4	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	6.4	5.7-6		.8		5.5-8.4	4.6-6.9	7.2-9.9	4.5-5.8	4.0-5.9	5.2-7.1	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	6.4	12.1-12.4		12.9-13.2		18.4-21.6	17.5-20.1	20.1-23.1	17.4-19.0	16.9-19.1	18.1-20.3	17.3-20.1	16.8-19.7

Activated Sludge - Discharge to Surface Waters - 100 MGD

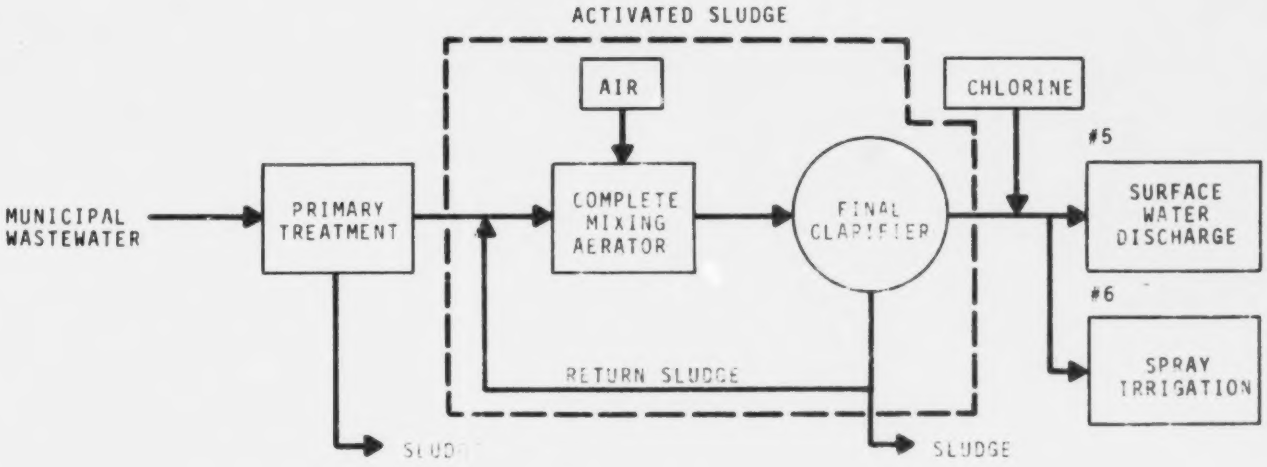
PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 5 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECON-DARY	TERTI-ARY	LIQUID DISPOSAL	UNIT OPERATION	1	2	3	4	5	6	7	8
		Activated Sludge		Surface Water	THICKENING:	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
					CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	40,000 kwh	1.19x 10^5 kwh				1.8x10^5 kwh 10x10^9 Btu	1.5x10^5 kwh 12x10^9 Btu	1.5x10^5 kwh 4.7x10^9 Btu	22,000 kwh	22,000 kwh	22,000 kwh	1.3x10^5 kwh	1.3x10^5 kwh
CONCRETE (CU YDS)	61,600	166,000		19,300		3520	3400	3560	102,000	102,000	102,000	102,000	102,000
STEEL (TONS)	5400	17,400		1270		2860	2780	3040	9400	9400	9400	9800	9800
CHEMICALS (LBS/DAY)				Chlorine 67,000		19,170-26,830	4500-5500	1170-5830	1170-5830	1170-5830	1170-5830	13,170-18,800	13,170-18,800
LAND (ACRES)		190				410-550	410-550	270-370	1370-1540	6000-27,000	26-36	820-1120	30-40
LABOR (MAN YRS/YR)	280	410				384-492	267-354	310-360	200-600	132-178	131-178	250-290	250-280
OUTPUTS - BOD (MG/L)	130	10-30											
(LBS/DAY)	1.04x10^6	.8-3x10^5											
SUSPENDED SOLIDS (MG/L)	80	10-30											
(LBS/DAY)	6.4x10^5	.8-3x10^5											
NUTRIENTS: P (MG/L)	14.3	10											
(LBS/DAY)	114,000	84,000				5-7x10^4	5-7x10^4	5-7x10^4	5-7x10^4	5-7x10^4	5-7x10^4	5-7x10^4	5-7x10^4
N (MG/L)	32	25											
(LBS/DAY)	2.56x10^5	2.1x10^5							.8-1x10^5	.8-1x10^5	.8-1x10^5	.8-1x10^5	.8-1x10^5
HEAVY METALS (LBS/DAY)		2500-50,000		2500-50,000		.13-3.3x10^4	.13-3.3x10^4	.13-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=250-400 NO_x=2500-3900	SO_2=440-670 Particulates=	HCl=80-120 4400-7000					
SLUDGES-% SOLIDS	5	1				100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	1.08x10^6	1.25x10^6				699,000	699,000	524,000	1.4x10^6	1.4x10^6	1.4 x10^6	1.4x10^6	1.4x10^6
SOLID WASTE (CU FT/YR)						12-18x10^3	3000-3600	800-3800	800-3800	800-3800		9-12x10^3	9-12x10^3
NUISANCE - ODOR	Poten-tial	Poten-tial				None	None	None	Potential	Potential	None	Potential	None
NOISE							Above Average						
TRAFFIC				1.7		18.5	18.0	13.6	35	35	.3	35.5	1
SAFETY (INJURIES/10^6 MAN-HRS)		41											
COSTS - CAPITAL ($ x 10^6)	117	143-150		2.16		34-47	50-68	110-150	44-52	7.1-9.7	16.1-21.8	36-48	35-47
RUNNING TOTAL CAPITAL ($ x 10^6)	117	260-267		262-269		296-316	312-337	372-419	306-321	269-279	278-291	298-317	297-316
LAND ($)		190,000				4.1-5.5x10^5	4.1-5.5x10^5	2.7-3.7x10^5	1.37-1.54x10^6	6-27x10^6	26,000-36,000	.82-1.1x10^6	30,000-40,000
RUNNING GRAND TOTAL ($ x 10^6)	117	260-267		262-269		296-316	312-337	372-419	307-322	275-306	278-291	299-318	297-316
OPERATING (¢/1000 GAL)	2.0	1.0		.5		4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	1.7-2.4	.22-.3	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.7	4.6-4.8		.07		1.1-1.5	1.6-2.2	3.6-4.8	1.5-1.7	.4-1.2	.52-.7	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	5.7	5.6-5.8		.6		5.5-8.4	4.6-6.9	7.2-9.9	4.6-5.8	2.1-3.6	.7-1.0	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	5.7	11.3-11.5		11.9-12.1		17.4-20.5	16.5-19.0	19.1-22.0	16.5-17.9	19.5-24.1	12.6-13.1	16.3-19.0	15.8-18.6

Activated Sludge - Discharge to Surface Waters - 1000 MGD

PROCESS PROFILE SHEETS FOR TREATMENT STRATEGY # 6

Activated Sludge with Land Application of Liquid Effluents


ACTIVATED SLUDGE
AIR
CHLORINE
#5
MUNICIPAL WASTEWATER
PRIMARY TREATMENT
COMPLETE MIXING AERATOR
FINAL CLARIFIER
SURFACE WATER DISCHARGE
#6
RETURN SLUDGE
SPRAY IRRIGATION
SLUDGE
SLUDGE

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 6 AT A FLOW RATE OF 1 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY	LIQUID DISPOSAL Land	UNIT OPERATION	1	2	3	4	5	6	7	8
					THICKENING:	FLOTATION		FLOTATION	FLOTATION	FLOTATION		FLOTATION	FLOTATION
					CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	250 kwh	933 kwh		800 kwh		181 kwh 10×10^6 Btu	151 kwh 12×10^6 Btu	146 kwh 4.7×10^6 Btu	22 kwh	22 kwh	Not Practical	126 kwh	126 kwh
CONCRETE (CU YDS)	98	175		41		22	19	360	360	360		362	562
STEEL (TONS)	9.6	25		22.7		50	50	36	36	36		38	58
CHEMICALS (LBS/DAY)				Chlorine 67		19-27	4.5-5.5	1.2-5.8	1.2-5.8	1.2-5.8		13.2-18.8	13.2-18.8
LAND (ACRES)		3.8		129		.43-.58	.41-.55	.255-.345	1.4-1.6	6-26		.86-1.2	.034-.05
LABOR (MAN YRS/YR)	2.6	1		1		2.2-2.6	1.7-2.1	2.0-2.4	1.2-2.1	1.4-1.9		1.6-2.2	2.6-3.5
OUTPUTS - BOD (MG/L)	130	10-30		.2-.6									
(LBS/DAY)	1040	83-250		1.7-5									
SUSPENDED SOLIDS (MG/L)	80	10-30		.7-2.0									
(LBS/DAY)	640	83-250		5.8-16.7									
NUTRIENTS: P (MG/L)	14.3	10		.1									
(LBS/DAY)	114	84		.8		50-75	50-75	50-75	50-75	50-75		50-75	50-75
N (MG/L)	32	25		3.8									
(LBS/DAY)	256	210		32					80-100	80-100		80-100	80-100
HEAVY METALS (LBS/DAY)		2.5-50		.2-3.2		1.3-33	1.3-33	1.3-33	1.5-33	1.5-93		1.5-33	1.5-33
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=.25-.4 NO_x=2.5-3.9	SO_2=.44-.67	HCl=.08-.12 Particulates=4.4-7					
SLUDGES-% SOLIDS	5	1				100	100	100	25-50	6-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	1080	1250				699	699	524	1400	1400		1400	1400
SOLID WASTE (CU FT/YR)						12-18	3-3.6	.8-3.8	.8-3.8	.8-3.8		9-12	9-12
NUISANCE - ODOR	Potential	Potential				None	None	None	Potential	Potential		Potential	None
NOISE													
TRAFFIC				Negligible		.02	.02	.01	.035	.035		.035	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)		19.6		Pathogen Last 1 mo									
COSTS - CAPITAL ($ x 10^6)	.455	.26-.3		.39-.57		.37-.445	.37-.51	.46-.465	.25-.26	.19-.25		.28-.3	.68-.7
RUNNING TOTAL CAPITAL ($ x 10^6)	.455	.715-.755		1.1-1.3		1.47-1.75	1.47-1.81	1.56-1.77	1.35-1.56	1.29-1.55		1.38-1.6	1.78-2.0
LAND ($)		3800		129,000		430-580	410-550	255-345	1400-1600	6000-26,000		860-1200	34-50
RUNNING GRAND TOTAL ($ x 10^6)	.455	.719-.759		1.24-1.46		1.61-1.91	1.61-1.97	1.7-1.93	1.49-1.72	1.44-1.74		1.52-1.76	1.92-2.16
OPERATING (¢/1000 GAL)	6	5.1		5-9		5.6-8.1	4.2-5.9	4.9-6.4	3.1-4.1	2.6-2.9		3.0-5.0	4.4-6.7
10% AMORTIZED (¢/1000 GAL)	14.6	8.5-9.8		16.7-22.5		11.9-14.3	11.9-16.4	14.8-15.0	8.0-8.4	6.3-8.9		9.0-9.6	21.9-22.5
TOTAL OPERATING (¢/1000 GAL)	20.6	13.6-14.9		21.7-31.5		17.5-22.4	16.1-22.3	19.7-21.4	11.1-12.5	8.9-11.8		12.0-14.6	26.3-29.2
RUNNING TOTAL (¢/1000 GAL)	20.6	34.2-35.5		55.9-67		73.4-89.4	72-89.3	75.6-88.4	67-79.5	64.8-78.8		67.9-81.6	82.2-96.2

Activated Sludge - Discharge to Land - 1 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 6 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECON-DARY Activated Sludge	TERTI-ARY	LIQUID DISPOSAL Land	UNIT OPERATION	1	2	3	4	5	6	7	8
					THICKENING:	FLOTATION		FLOTATION	FLOTATION	FLOTATION		FLOTATION	FLOTATION
					CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270 kwh	3734 kwh		4600 kwh		1810 kwh $100x10^6$ Btu	1510 kwh $123x10^6$ Btu	1460 kwh $47x10^6$ Btu	220 kwh	220 kwh	Not Practical	1260 kwh	1260 kwh
CONCRETE (CU YDS)	256	2100		252		30	28	34	1210	1210		1220	1220
STEEL (TONS)	75	290		66.7		55	56	70	119	118		123	123
CHEMICALS (LBS/DAY)				Chlorine 670		192-268	45-55	11-58	11-58	12-58		132-188	132-188
LAND (ACRES)		19		1290		4.3-5.8	4.1-5.5	2.7-3.7	13.7-15.4	13.7-15.4		8.2-11.2	.34-.5
LABOR (MAN YRS/YR)	3.2	7.9		10		5.6-7.5	4.1-5.8	4.3-6.3	3.4-7.9	3.4-7.9		4.1-4.8	4.8-5.5
OUTPUTS - BOD (MG/L)	130	10-30		.2-.6									
(LBS/DAY)	10,400	830-2500		17-50									
SUSPENDED SOLIDS (MG/L)	80	10-30		.7-2.0									
(LBS/DAY)	6400	830-2500		58-167									
NUTRIENTS: P (MG/L)	14.3	10		.1									
(LBS/DAY)	1140	840		8.3		500-700	500-700	500-700	500-700	500-700		500-700	500-700
N (MG/L)	32	25		3.8									
(LBS/DAY)	2560	2100		320					800-1000	800-1000		800-1000	800-1000
HEAVY METALS (LBS/DAY)		25-500		2-32		13-326	13-326	13-326	15-330	15-330		15-330	15-330
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=2.5-4 NO_x=25-39	SO_2=4.4-6.7 Particulates=44-70	HCl=.8-1.2					
SLUDGES-% SOLIDS	5	1				100	100	100	25-50	6-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	10,800	12,500				6990	6990	5240	14,000	14,000		14,000	14,000
SOLID WASTE (CU FT/YR)						120-180	30-36	7-38	7-38	8-38		90-120	90-120
NUISANCE - ODOR	Potential	Potential				None	None	None	Potential	Potential		Potential	None
NOISE							Above Average						
TRAFFIC				.02		.18	.18	.13	.35	.35		.35	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)		28.5		Pathogens Last 1 mo.									
COSTS - CAPITAL ($ x 10^6)	2.21	1.9-2		3.9-5.7		1-1.3	1.2-1.3	1.8-2.1	.57-.64	.30-.40		.69-.85	1.1-1.3
RUNNING TOTAL CAPITAL ($ x 10^6)	2.21	4.11-4.21		8.0-9.9		9.0-11.2	9.2-11.2	9.8-12.0	8.6-10.5	8.3-10.3		8.7-10.8	9.1-11.2
LAND ($)		19,000		$1.29x10^6$		4300-5800	4100-5500	2700-3700	13,700-15,400	$.6-2.6x10^5$		8200-11,200	340-500
RUNNING GRAND TOTAL ($ x 10^5)	2.21	4.13-4.23		9.3-11.2		10.3-12.5	10.5-12.5	11.1-13.3	9.9-11.9	9.7-11.9		10-12.1	10.4-12.5
OPERATING (¢/1000 GAL)	4	3.4		5-9		4.6-7.0	3.15-4.85	3.8-5.3	3.1-4.1	2.6-2.9		3.2-5.4	3.0-5.2
10% AMORTIZED (¢/1000 GAL)	7.1	6.1-6.4		16.7-22.5		3.2 4.2	3.9-4.2	5.8-6.8	1.8-2.1	1.1-1.3		2.2-2.7	3.5-4.2
TOTAL OPERATING (¢/1000 GAL)	11.1	9.5-9.8		21.7-31.5		7.8-11.2	7.1-9.1	9.6-12.1	4.9-6.2	3.7-4.2		5.4-8.1	6.5-9.4
RUNNING TOTAL (¢/1000 GAL)	11.1	20.6-20.9		42.3-52.4		50.1-63.6	49.4-61.5	51.9-64.5	47.2-58.6	46.0-56.6		47.7-60.5	48.8-61.8

Activated Sludge - Discharge to Land - 10 MGD

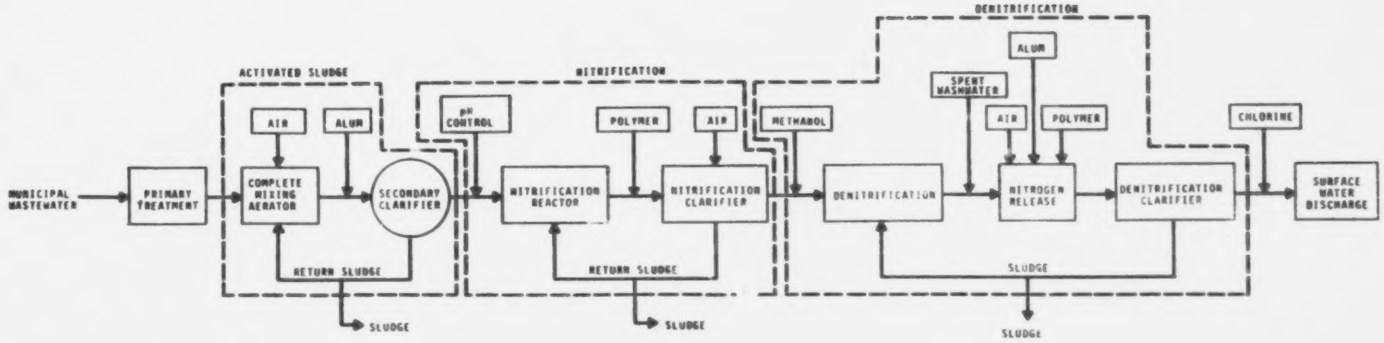
PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 6 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	1	2	3	4	5	6	7	8
					THICKENING:	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
					CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
		Activated Sludge		Land	DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	4000 kwh	11,900 kwh		18,800 kwh		18,100 kwh 1x10^9 Btu	15,100 kwh 1.2x10^9 Btu	14,600 kwh 470x10^6 Btu	2200 kwh	2200 kwh	2200 kwh	12,600 kwh	12,600 kwh
CONCRETE (CU YDS)	6240	14,000		1000		365	342	373	10,200	10,200	10,200	10,200	10,200
STEEL (TONS)	545	1600		265		300	295	340	940	940	940	980	980
CHEMICALS (LBS/DAY)				Cl_2-6700		1917-2683	450-550	117-583	117-583	117-583	117-583	1317-1880	1317-1880
LAND (ACRES)		38		12,900		41-55	41-55	27-37	137-154	603-2603	2.6-3.6	82-112	3-4
LABOR (MAN YRS/YR)	28	41		55		38.4-49.2	26.7-35.4	31-36	20-60	13.6-18.4	13.6-18.4	25-29	25-28
OUTPUTS - BOD (MG/L)	130	10-30		.2-.6									
(LBS/DAY)	1.04x10^5	.8-3x10^4		170-500									
SUSPENDED SOLIDS (MG/L)	80	10-30		.7-2.0									
(LBS/DAY)	64,000	.8-3x10^4		580-1670									
NUTRIENTS: P (MG/L)	14.3	10		0.1									
(LBS/DAY)	11,400	8400		83		5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000
N (MG/L)	32	25		3.8									
(LBS/DAY)	25,600	21,000		3200					8000-10,000	8000-10,000	8000-10,000	8000-10,000	8000-10,000
HEAVY METALS (LBS/DAY)		250-5000		20-320		125-3260	125-3260	125-3260	150-3300	150-3300	150-3300	150-3300	150-3300
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=25-40 NO_x=250-390	SO_2=44-67 Particulates =	HCl=8-12 440-700					
SLUDGES-% SOLIDS	5	1				100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	108,000	125,000				69,900	69,900	52,400	140,000	140,000	140,000	140,000	140,000
SOLID WASTE (CU FT/YR)						1200-1800	300-360	80-380	80-380	80-380		900-1200	900-1200
NUISANCE - ODOR	Potential	Potential				None	None	None	Potential	Potential	None	Potential	None
NOISE							Above Average						
TRAFFIC				.17		1.75	1.75	1.3	3.5	3.5	.03	3.5	.1
SAFETY (INJURIES/10^6 MAN-HRS)		41		Pathogens Last 1 mo									
COSTS - CAPITAL ($ x 10^6)	11.7	14-15		39-57		3.4-4.7	5-6.8	11-15	4.4-5.2	5.1-6.9	14.7-19.9	3.7-4.9	3.5-4.7
RUNNING TOTAL CAPITAL ($ x 10^6)	11.7	25.7-26.7		64.7-83.7		68.1-88.4	69.7-90.5	75.7-98.7	69.1-88.9	69.8-90.6	79.4-103.6	68.4-88.6	68.2-88.4
LAND ($)		38,000		12.9x10^6		41,000-55,000	41,000-55,000	27,000-37,000	1.32-1.54 x10^5	.6-2.6x10^6	2600-3600	.82-1.1x10^5	3000-4000
RUNNING GRAND TOTAL ($ x 10^6)	11.7	25.7-26.7		77.6-96.6		81-101.4	82.6-103.5	88.6-111.6	82.1-102	83.3-106.1	92.3-116.5	81.4-101.6	81.1-101.3
OPERATING (¢/1000 GAL)	2.6	1.2		5-9		4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	2.2-2.8	.54-.73	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.8	4.5-4.8		16.7-22.5		1.1-1.5	1.6-2.2	3.6-4.8	1.4-1.7	1.8-3.1	4.7-6.4	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	6.4	5.7-6		21.7-31.5		5.5-8.4	4.6-6.9	7.2-9.9	4.5-5.8	4.0-5.9	5.2-7.1	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	6.4	12.1-12.4		33.8-43.9		39.3-52.3	38.4-50.8	41-53.8	38.3-49.7	37.8-49.8	39-51	38.2-50.8	37.7-50.4

Activated Sludge - Discharge to Land - 100 MGD

PROCESS PROFILE SHEETS FOR TREATMENT STRATEGY # 7

Biological-Chemical Treatment



MUNICIPAL WASTEWATER
PRIMARY TREATMENT
ACTIVATED SLUDGE
AIR
ALUM
COMPLETE MIXING AERATOR
SECONDARY CLARIFIER
RETURN SLUDGE
SLUDGE
NITRIFICATION
pH CONTROL
POLYMER
AIR
NITRIFICATION REACTOR
NITRIFICATION CLARIFIER
RETURN SLUDGE
SLUDGE
DENITRIFICATION
METHANOL
SPENT WASHWATER
ALUM
AIR
POLYMER
DENITRIFICATION
NITROGEN RELEASE
DENITRIFICATION CLARIFIER
SLUDGE
SLUDGE
CHLORINE
SURFACE WATER DISCHARGE

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 7 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge with Chem Add	TERTIARY Nitrification Denitrification	LIQUID DISPOSAL Surface Water	UNIT OPERATION THICKENING CONDITIONING DEWATERING DISPOSAL	1 GRAVITY CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 GRAVITY PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 GRAVITY DIGESTION SAND DRYING LANDFILL	5 GRAVITY DIGESTION LAND SPREADING	6 DIGESTION OCEAN DUMPING	7 GRAVITY DIGESTION VACUUM FILTRATION LANDFILL	8 GRAVITY DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270 kwh	3734 kwh	315 kwh			3180 kwh 212x10^6 Btu	3000 kwh 306x10^6 Btu	1950 kwh 75x10^6 Btu	100 kwh	100 kwh	Not Practical	2640 kwh	2640 kwh
CONCRETE (CU YDS)	756	2100	2860	252		50	45	57	1800	1800		1820	1820
STEEL (TONS)	75	290	250	16.7		95	95	120	190	190		200	200
CHEMICALS (LBS/DAY)		Alum 12,600	Methanol 4200	Chlorine 590		340-370	53.5-73.5		*			170-210	170-210
LAND (ACRES)		19	10			8.4-11.4	8.1-11.3	5-6.6	17-19	94-376		11-15	.43-.58
LABOR (MAN YRS/YR)	7.9	2.5	7			6.4-9.2	5.6-8.3	4.3-7.8	3.3-10	3.1-3.7		4.8-7.0	5.5-5.9
OUTPUTS - BOD (MG/L)	130	13	8										
(LBS/DAY)	10,400	1090	670										
SUSPENDED SOLIDS (MG/L)	80	8.8	7.1										
(LBS/DAY)	6400	737	593										
NUTRIENTS: P (MG/L)	14.3	.3	.3										
(LBS/DAY)	1140	25	25			1000-1400	1000-1400	1000-1400	1000-1400	1000-1400		1000-1400	1000-1400
N (MG/L)	32	25	2										
(LBS/DAY)	2560	2100	168						800-1000	800-1000		800-1000	800-1000
HEAVY METALS (LBS/DAY)			200-300	200-300		36-750	36-750	36-750	36-750	36-750		36-750	36-750
ATMOSPHERIC EMISSIONS (LBS/DAY)													
SLUDGES-% SOLIDS	5	2-5	<1			100	100	100	25-50	5-7		15-30	15-30
TOTAL DRY WT. (LBS/DAY)	10,800	25,100	1700			14,100	14,100	8460	18,800	18,800		18,800	18,800
SOLID WASTE (CU FT/YR)		8278				223-243	35-48					112-138	112-138
NUISANCE - ODOR	Potential	Potential	Potential			None	None	None	Potential	Potential		Potential	None
NOISE							Above Average						
TRAFFIC				.43		.35	.35	.21	.47	.47		.47	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)			28.5										
COSTS - CAPITAL ($ x 10^6)	2.21	1.9-2	2.83	.087		1.6-2.2	1.43-1.93	1.3-1.7	.761-.83	.44-.6		1.2-1.6	1.6-[illegible].2
RUNNING TOTAL CAPITAL ($ x 10^6)	2.21	4.1-4.2	6.9-7	7-7.1		8.6-9.3	8.4-9	8.3-8.8	7.8-7.9	7.4-7.7		8.2-8.7	8.6-9.3
LAND ($)		19,000	10,000			8400-11,400	8100-11,300	5000-6600	3300-10,000	.94-3.8x10^5		11,000-15,000	430-580
RUNNING GRAND TOTAL ($ x 10^6)	2.21	4.1-4.2	6.9	7-7.1		8.6-9.3	8.4-9	8.3-8.8	7.8-7.9	7.5-8.1		8.2-8.7	8.6-9.3
OPERATING (¢/1000 GAL)	4	6.4	6.5	.9		4-7.3	3.8-6.5	2.9-4.8	2.5-3.2	1.9-2.4		3-4.7	2.8-4.9
10% AMORTIZED (¢/1000 GAL)	7.1	6.1-6.4	9.2	.3		5.1-7.1	4.6-6.2	4.2-5.5	2.4-2.7	1.7-3.2		3.9-5.1	5.1-7.1
TOTAL OPERATING (¢/1000 GAL)	11.1	12.5-12.8	15.7	1.2		9.8-14.4	8.4-12.7	7.1-10.3	4.9-5.9	3.6-5.6		6.9-9.8	7.9-12.0
RUNNING TOTAL (¢/1000 GAL)	11.1	23.6-23.9	39.3-39.6	40.5-40.8		50.3-5[illegible].2	48.9-53.5	47.6-51.1	45.4-46.7	44.1-46.4		47.4-50.6	48.4-52.8

Biological-Chemical Treatment - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 2 AT A FLOW RATE OF 100 MGD

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	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge with Chem Add	TERTIARY Nitrification Denitrification	LIQUID DISPOSAL Surface Water	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL	1 GRAVITY CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 GRAVITY PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 GRAVITY DIGESTION SAND DRYING LANDFILL	5 GRAVITY DIGESTION LAND SPREADING	6 GRAVITY DIGESTION OCEAN DUMPING	7 GRAVITY DIGESTION VACUUM FILTRATION LANDFILL	8 GRAVITY DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	4000 KWH	11,900 KWH	3140 KWH			31,800 kwh 2.1×10^9 Btu	10,000 kwh 1.5×10^9 Btu	19,500 kwh 250×10^6 Btu	1000 kwh	1000 kwh	11000 kwh	26,400 kwh	[illegible] kwh
CONCRETE (CU YDS)	6240	14,000	26,700	2120		620	580	635	17,300	17,300	17,300	17,300	17,300
STEEL (TONS)	545	1600	1900	140		510	500	580	1590	1590	1590	1660	1660
CHEMICALS (LBS/DAY)		Alum 126,000	Methanol 42,000	Chlorine 5900		3400-3700	545-735					1700-2100	1700-2100
LAND (ACRES)		38	20			83-113	81-109	50-66	182-197	857-3431	1.7-4.9	117-159	4.3-5.8
LABOR (MAN YRS/YR)	24.3	15	17.2			49-74	41-62	30-36	22-62	17-23	15.3-20.7	36.6-49.5	28.1-37.9
OUTPUTS - BOD (MG/L)	130	23	8										
(LBS/DAY)	104,000	10,900	6700										
SUSPENDED SOLIDS (MG/L)	80	8.8	7.1										
(LBS/DAY)	64,000	7370	5930										
NUTRIENTS P (MG/L)	14.3	.3	.3										
(LBS/DAY)	11,400	250	250			$1-1.4 \times 10^4$	$1-1.4 \times 10^4$	$1-1.4 \times 10^4$	$1-1.4 \times 10^4$	$1-1.4 \times 10^4$	$1-1.4 \times 10^4$	$1-1.4 \times 10^4$	$1-1.4 \times 10^4$
N (MG/L)	32	25	2.0										
(LBS/DAY)	25,600	21,000	1680						8000-10,000	8000-10,000	8000-10,000	8000-10,000	8000-10,000
HEAVY METALS (LBS/DAY)			2000-3000	2000-3000		360-7500	360-7500	360-7500	360-7500	360-7500	360-7500	360-7500	360-7500
ATMOSPHERIC EMISSIONS (LBS/DAY)													
SLUDGES-% SOLIDS	5	2-5	1			100	100	100	25-50	5-7	5-7	15-30	15-30
TOTAL DRY WT (LBS/DAY)	108,000	2.51×10^5	17,000			141,000	141,000	84,600	188,000	188,000	188,000	188,000	188,000
SOLID WASTE (CU FT/YR)		82,780				2230-2430	350-480					1120-1380	1120-1380
NUISANCE - ODOR	Potential	Potential	Potential			None	None	None	Potential	Potential	None	Potential	None
NOISE							Above Average						
TRAFFIC				4.3		3.5	3.5	2.1	4.7	4.7	None	4.7	.1
SAFETY (INJURIES/10^6 MAN-HRS)			41										
COSTS - CAPITAL ($ × 10^6)	11.7	15-16	28.3	.42		7.0-9.6	6.4-8.8	8-10	6.1-6.8	6.5-8.8	15.1-20.3	6.4-8.6	8.1-8.3
RUNNING TOTAL CAPITAL $ × 10^6)	11.7	26.2-27.7	55-56	55.4-56.4		62.4-66	61.8-65.2	63.4-66.4	61.5-63.2	61.9-65.2	70.5-76.7	61.8-65	63.5-64.7
LAND ($)		38,000	20,000			$.83-1.13 \times 10^5$	$.81-1.1 \times 10^5$	50,000-66,000	$1.82-1.97 \times 10^5$	$.86-3.4 \times 10^6$	3700-4900	$1.2-1.6 \times 10^5$	4300-5800
RUNNING GRAND TOTAL ($ × 10^6)	11.7	26.7-27.7	55-56	55.4-56.4		62.5-66.1	61.9-65.3	63.4-66.5	61.7-63.4	62.8-68.6	70.5-76.7	61.9-65.2	63.5-64.7
OPERATING (¢/1000 GAL)	2.6	4.5	6.3	.7		3.8-7.0	3.6-6.2	3.2-5.1	2.5-3.2	1.6-2.1	.6-.75	3-4.7	1.6-3.0
10% AMORTIZED (¢/1000 GAL)	3.8	4.8-5.1	9.1	.13		2.3-3.1	2.1-2.8	2.6-3.2	2.0-2.2	2.4-3.9	4.9-6.5	2.1-2.8	2.6-2.7
TOTAL OPERATING (¢/1000 GAL)	6.4	9.3-9.6	15.4	.8		6.1-10.1	5.7-9.0	5.8-8.3	4.5-5.4	4.0-6.0	5.5-7.3	5.5-7.5	4.2-5.7
RUNNING TOTAL (¢/1000 GAL)	6.4	15.7-16	31.1-31.4	31.9-32.2		38-42.3	37.6-41.2	37.7-40.5	36.4-37.6	35.9-38.2	37.4-39.5	37.4-39.7	36.1-37.9

Biological-Chemical Treatment - 100 MGD

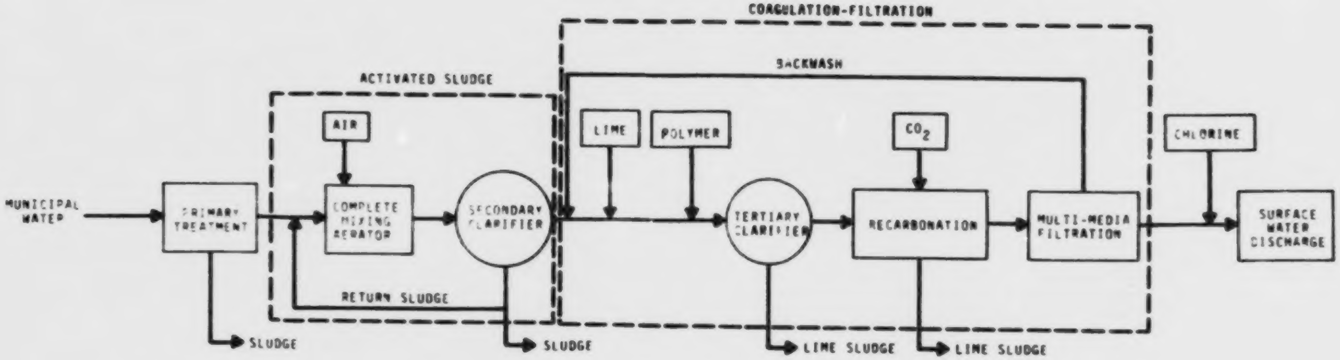
PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 7 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge with Chem Add	TERTIARY Nitrification Dentrification	LIQUID DISPOSAL Surface Water	UNIT OPERATION	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY		GRAVITY	GRAVITY	GRAVITY	GRAVITY	GRAVITY	GRAVITY
					CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	40,000 kwh	119,000 kwh	31,400 kwh			3x10^{5} kwh 21x10^{9} Btu	3x10^{5} kwh 31x10^{9} Btu	1.9x10^{5} kwh 7.5x10^{9} Btu	10,000 kwh	10,000kwh	10,000 kwh	2.6x10^{5} kwh	2.6x10^{5} kwh
CONCRETE (CU YDS)	61,600	166,000	244,000	19,300		5630	5450	5700	170,000	170,000	170,000	170,000	170,000
STEEL (TONS)	5400	17,500	26,000	1270		4580	4450	4570	15,000	15,000	15,000	15,700	15,700
CHEMICALS (LBS/DAY)		Alum 1.26x10^{6}	Methanol 420,000	Chlorine 59,000		34,000-37,000	5450-7350					17,000-21,000	17,000-21,000
LAND (ACRES)		380	200			830-1110	810-1090	500-660	1820-1970	8577-34,310	42.1-56.9	1170-1590	43-58
LABOR (MAN YRS/YR)	243	150	172			490-740	410-620	300-560	220-620	154-208	154-208	366-495	281-379
OUTPUTS - BOD (MG/L)	130	13	8										
(LBS/DAY)	1.04x10^{6}	109,000	67,000										
SUSPENDED SOLIDS (MG/L)	80	8.8	7.1										
(LBS/DAY)	640,000	73,700	59,300										
NUTRIENTS P (MG/L)	14.3	.3	.3										
(LBS/DAY)	114,000	2500	2500			1-1.4x10^{5}	1-1.4x10^{5}	1-1.4x10^{5}	1-1.4x10^{5}	1-1.4x10^{5}	1-1.4x10^{5}	1-1.4x10^{5}	1-1.4x10^{5}
N (MG/L)	32	25	2										
(LBS/DAY)	256,000	210,000	16,800						.8-1x10^{5}	.8-1x10^{5}	.8-1x10^{5}	.8-1x10^{5}	.8-1x10^{5}
HEAVY METALS (LBS/DAY)			2-3x10^{4}	2-3x10^{4}		.4-7.5x10^{4}	.4-7.5x10^{4}	.4-7.5x10^{4}	.4-7.5x10^{4}	.4-7.5x10^{4}	.4-7.5x10^{4}	.4-7.5x10^{4}	.4-7.5x10^{4}
ATMOSPHERIC EMISSIONS (LBS/DAY)													
SLUDGES-% SOLIDS	5	2-5	<1			100	100	100	25-50	5-7	5-7	15-30	15-30
TOTAL DRY WT. (LBS/DAY)	1.08x10^{6}	2.51x10^{6}	170,000			1.41x10^{6}	1.41x10^{6}	846,000	1.88x10^{6}	1.88x10^{6}	1.88x10^{6}	1.88x10^{6}	1.88x10^{6}
SOLID WASTE (CU FT/YR)		8.3x10^{5}				22-24x10^{4}	35-48x10^{3}					11-14x10^{4}	11-14x10^{4}
NUISANCE - ODOR	Potential	Potential	Potential			None	None	None	Potential	Potential	None	Potential	None
NOISE							Above Average						
TRAFFIC				43		36.3	35.3	21.2	47	47	None	48	1
SAFETY (INJURIES/10^{6} MAN-HRS)			41										
COSTS - CAPITAL ($ x 10^{6})	117	150-160	283	2.16		71-97	64-88	80-100	62-68	67.6-90	17-24	65-88	81-83
RUNNING TOTAL CAPITAL ($ x 10^{6})	117	267-277	550-560	552-562		623-659	616-650	632-662	614-630	619-652	569-586	617-650	633-645
LAND ($)		380,000	200,000			.83-1.13x10^{5}	.81-1.1x10^{6}	5-6.6x10^{5}	1.82-1.97x10^{6}	8.6x34x10^{6}	1.54-2.1x10^{5}	1.2-1.6x10^{6}	.43-.58x10^{5}
RUNNING GRAND TOTAL ($ x 10^{6})	117	267-277	550-560	552-562		623-659	617-651	632-662	616-632	628-686	569-586	618-652	633-645
OPERATING (¢/1000 GAL)	2.6	4	6.3	.5		3.8-7.0	3.6-6.2	3.2-5.1	2.5-3.2	1.1-1.6	.2-.28	3-4.7	1.6-3.0
10% AMORTIZED (¢/1000 GAL)	3.8	4.8-5.1	9.1	.1		2.3-3.1	2.1-2.8	2.6-3.2	2.0-2.2	2.4-3.0	.56-.77	2.1-2.8	2.6-2.7
TOTAL OPERATING (¢/1000 GAL)	6.4	8.8-9.1	15.4	.6		6.1-10.1	5.7-9.0	5.8-8.3	4.5-5.4	3.5-4.6	.8-1.1	5.1-7.5	4.2-5.7
RUNNING TOTAL (¢/1000 GAL)	6.4	15.2-15.5	30.6-30.9	31.2-31.5		37.3-41.6	36.9-40.5	37-39.8	35.7-36.9	34.7-36.1	32-32.6	36.3-39	35.4-37.2

Biological-Chemical Treatment - 1000 MGD

PROCESS PROFILE SHEETS FOR TREATMENT STRATEGY # 8

Activated Sludge-Coagulation-Filtration



COAGULATION-FILTRATION
BACKWASH
ACTIVATED SLUDGE
AIR
LIME
POLYMER
CO_2
CHLORINE
MUNICIPAL WATER
PRIMARY TREATMENT
COMPLETE MIXING AERATOR
SECONDARY CLARIFIER
TERTIARY CLARIFIER
RECARBONATION
MULTI-MEDIA FILTRATION
SURFACE WATER DISCHARGE
RETURN SLUDGE
SLUDGE
SLUDGE
LIME SLUDGE
LIME SLUDGE

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 8 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	9	1	2	3	4	5	6	7	8
		Activated Sludge	Coagulation Filtration	Surface Water	THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION		FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270 kwh	3734 kwh	5480 kwh			3125 kwh 265×10^6 Btu	1810 kwh 100×10^6 Btu	1510 kwh 120×10^6 Btu	1460 kwh 47×10^6 Btu	220 kwh	220 kwh	Not Practical	1260 kwh	1260 kwh
CONCRETE (CU YDS)	756	2100	5160	252		68	30	28	34	1210	1210		1220	1220
STEEL (TONS)	75	290	225	16.7		70	55	56	70	120	120		120	125
CHEMICALS (LBS/DAY)			Lime=21,000 CO_2=26,500	Polymer=21 Cl_2=250			192-268	45-55	11-58	11-58	12-58		132-188	132-188
LAND (ACRES)		19	10			19.9-26.9	4.1-5.5	4.1-5.5	2.7-3.7	13.7-15.4	60-260		8.2-11.2	.34-.5
LABOR (MAN YRS/YR)	3.2	7.9	4.3			8.5-11.5	5.6-7.5	4.1-5.8	4.3-6.3	3.4-7.9	10.2-13.9		4.1-4.8	4.8-5.5
OUTPUTS - BOD (MG/L)	130	10-30	3											
(LBS/DAY)	10,400	830-2500	252											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	6400	830-2500	25											
NUTRIENTS: P (MG/L)	16.3	10	.1											
(LBS/DAY)	1140	840	8.4			800-1150	500-700	500-700	500-700	500-700	500-700		500-700	500-700
N (MG/L)	32	25	17											
(LBS/DAY)	2560	2100	1428							800-1000	800-1000		800-1000	800-1000
HEAVY METALS (LBS/DAY)		25-500	Negligible			25-500	13-326	13-326	13-326	15-330	15-330		15-330	15-330
ATMOSPHERIC EMISSIONS (LBS/DAY)							SO_2=4.4-6.7 NO_x=25-39	HCl-.8-1.2 Particulates=44-70	Metals=2.5-4					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	10,800	12,500	44,100			35,300	6990	6990	5240	14,000	14,000		14,000	14,000
SOLID WASTE (CU FT/YR)			13,810				120-180	30-36	7-38	7-38	8-38		90-120	90-120
NUISANCE - ODOR	Potential	Potential				None	None	None	None	Potential	Potential		Potential	Potential
NOISE								Above Average						
TRAFFIC				.54		.88	.18	.18	.13	.35	.35		.35	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)						28.5								
COSTS - CAPITAL ($\$ \times 10^6$)	2.21	1.9-2	2	.043		1.4-1.9	1-1.3	1.2-1.3	1.8-2.1	.57-.64	.30-.40		.69-.85	1.1-1.3
RUNNING TOTAL CAPITAL ($\$ \times 10^6$)	2.21	4.11-4.21	6.1-6.2	6.2-6.3		7.6-8.2	8.6-9.5	8.8-9.5	9.4-10.3	8.2-8.8	7.9-8.6		8.3-9.1	8.7-9.5
LAND ($)		19,000	10,000			$19.9-26.9 \times 10^3$	4100-5500	4100-5500	2700-3700	13,700-15,400	$.6-2.6 \times 10^5$		8200-11,200	340-500
RUNNING GRAND TOTAL ($\$ \times 10^6$)	2.21	4.11-4.23	6.1-6.2	6.2-6.3		7.6-8.2	8.6-9.5	8.8-9.5	9.4-10.3	8.2-8.9	8-8.9		8.3-9.1	8.7-9.5
OPERATING (¢/1000 GAL)	4	3.4	7.7	.9		4.1-7.0	4.6-7.0	3.15-4.85	3.8-5.3	3.1-4.1	2.6-2.9		3.2-5.4	3.0-5.2
10% AMORTIZED (¢/1000 GAL)	7.1	6.1-6.4	6.5	.1		4.5-6.1	3.2-4.2	3.9-4.2	5.8-6.8	1.8-2.1	1.1-2.1		2.2-2.7	3.5-4.2
TOTAL OPERATING (¢/1000 GAL)	11.1	9.5-9.8	14.2	1.0		8.6-13.1	7.8-11.2	7.1-9.1	9.6-12.1	4.9-6.2	3.7-5.0		5.4-8.1	6.5-9.4
RUNNING TOTAL (¢/1000 GAL)	11.1	20.6-20.9	34.8-35.1	35.8-36.1		44.4-49.2	52.2-60.4	51.5-58.3	54.0-61.3	49.3-55.4	48.1-54.2		49.8-57.3	50.9-58.6

Activated Sludge-Coagulation-Filtration with
Filtration-Incineration of Chemical Sludges - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 8 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	10	1	2	3	4	5	6	7	8
		Activated Sludge	Coagulation Filtration	Surface Water	THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION		FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270 kwh	3734 kwh	5480 kwh			8150 kwh 464x10^6 Btu	1810 kwh 100x10^6 Btu	1510 kwh 120x10^6 Btu	1460 kwh 47x10^6 Btu	220 kwh	220 kwh	Not Practical	1260 kwh	1260 kwh
CONCRETE (CU YDS)	756	2100	760	252		95	30	28	36	1210	1210		1220	1220
STEEL (TONS)	75	290	225	16.7		98	55	56	70	120	120		120	125
CHEMICALS (LBS/DAY)			Lime=6300 CO$_2$=26,500	Polymers-[illegible] Chlorine-[illegible]			192-268	45-55	11-58	11-58	12-58		132-188	132-188
LAND (ACRES)		19	10			12-16.2	4.1-5.5	4.1-5.5	2.7-3.7	13.7-15.4	60-260		8.2-11.2	.34-.5
LABOR (MAN YRS/YR)	3.2	7.9	4.3			13.3-17.9	5.6-7.5	4.1-5.8	4.3-6.3	3.4-7.9	10.2-13.9		4.1-4.8	4.8-5.5
OUTPUTS - BOD (MG/L)	130	10-30	3											
(LBS/DAY)	10,400	830-2500	252											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	6400	830-2500	25											
NUTRIENTS: P (MG/L)	14.3	10	.1											
(LBS/DAY)	1140	840	8.4			1600-2300	500-700	500-700	500-700	500-700	500-700		500-700	500-700
N (MG/L)	32	25	17											
(LBS/DAY)	2560	2100	1428							800-1000	800-1000		800-1000	800-1000
HEAVY METALS (LBS/DAY)		25-500	Negligible			25-500	13-326	13-326	13-326	15-330	15-330		15-330	15-330
ATMOSPHERIC EMISSIONS (LBS/DAY)							SO$_2$=4.4-6.7 NO$_x$=25-39	HCl=.8-1.2 Particulates=46-70	Metals=2.5-4					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	10,800	12,500	77,400			20,600	6990	6990	5240	14,000	14,000		16,000	16,000
SOLID WASTE (CU FT/YR)			4153				120-180	30-36	7-38	7-38	8-38		90-120	90-120
NUISANCE - ODOR	Potential	Potential				None	None	None	None	Potential	Potential		Potential	Potential
NOISE								Above Average						
TRAFFIC				.17		.5	.18	.18	.13	.35	.35		.35	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)						28.5								
COSTS - CAPITAL ($ x 10^6)	2.21	1.9-2	2	.063		2-2.7	1-1.3	1.2-1.3	1.8-2.1	.57-.64	.30-.40		.69-.85	1.1-1.3
RUNNING TOTAL CAPITAL ($ x 10^6)	2.21	4.11-4.21	6.1-6.2	6.2-6.3		8.2-9	9.2-10.3	9.4-10.3	10-11.2	8.8-9.6	8.5-9.4		8.9-9.9	9.3-10.3
LAND ($)		19,000	10,000			12-16.2x10^3	4100-5500	4100-5500	2700-3700	13,700-15,400	.6-2.6x10^5		8200-11,200	340-500
RUNNING GRAND TOTAL ($ x 10^6)	2.21	4.13-4.23	6.1-6.2	6.2-6.3		8.2-9	9.2-10.3	9.4-10.3	10-11.2	8.8-9.7	8.6-9.7		8.9-9.9	9.3-10.3
OPERATING (¢/1000 GAL)	4.0	3.4	7.7	.9		4.5-10.8	4.6-7.0	3.15-4.85	3.8-5.3	3.1-4.1	2.6-2.9		3.2-5.4	3.0-5.2
10% AMORTIZED (¢/1000 GAL)	7.1	6.1-6.4	6.5	.1		6.5-8.7	3.2-4.2	3.9-4.2	5.8-6.8	1.8-2.1	1.1-2.1		2.2-2.7	3.5-4.2
TOTAL OPERATING (¢/1000 GAL)	11.1	9.5-9.8	14.2	1.0		11-19.5	7.8-11.2	7.1-9.1	9.6-12.1	4.9-6.2	3.7-5.0		5.4-8.1	6.5-9.4
RUNNING TOTAL (¢/1000 GAL)	11.1	20.6-20.9	34.8-35.1	35.8-36.1		46.8-55.6	54.6-66.8	53.9-64.7	56.4-67.7	51.7-61.8	50.5-60.6		52.2-63.7	53.3-65

Activated Sludge-Coagulation-Filtration with
Filtration-Recalcination of Chemical Sludge - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 8 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	11	1	2	3	4	5	6	7	8
		Activated Sludge	Coagulation Filtration	Surface Water	THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION		FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270 kwh	3734 kwh	5480 kwh			1690 kwh 265x10⁶ Btu	1810 kwh 100x10⁶ Btu	1510 kwh 120x10⁶ Btu	1460 kwh 47x10⁶ Btu	220 kwh	220 kwh	Not Practical	1260 kwh	1260 kwh
CONCRETE (CU YDS)	756	2100	760	252		32	30	28	34	1210	1210		1220	1220
STEEL (TONS)	75	290	225	16.7		38	55	56	70	120	120		120	125
CHEMICALS (LBS/DAY)			Polymer-21 Lime-21,000	CO_2-26,500 Cl_2-420			192-268	45-55	11-58	11-58	12-58		132-188	132-188
LAND (ACRES)		19	10			20-26	4.1-5.5	4.1-5.5	2.7-3.7	13.7-15.4	60-260		8.2-11.2	.34-.5
LABOR (MAN YRS/YR)	3.2	7.9	4.3			7.2-9.8	5.6-7.5	4.1-5.8	4.3-6.3	3.4-7.9	10.2-13.9		4.1-4.8	4.8-5.5
OUTPUTS - BOD (MG/L)	130	10-30	3											
(LBS/DAY)	10,400	830-2500	252											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	6400	830-2500	25											
NUTRIENTS: P (MG/L)	14.3	10	.1											
(LBS/DAY)	1140	840	8.4			800-1150	500-700	500-700	500-700	500-700	500-700		500-700	500-700
N (MG/L)	32	25	17											
(LBS/DAY)	2560	2100	1428							800-1000	800-1000		800-1000	800-1000
HEAVY METALS (LBS/DAY)		25-500	Negligible			25-500	13-326	13-326	13-326	15-330	15-330		15-330	15-330
ATMOSPHERIC EMISSIONS (LBS/DAY)							SO_2=4.4-6.7 Particulates=44-70	HCl=.8-1.2	Metals=250-400 NO_x=2500-3900					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	10,900	12,500	44 100			35,300	6990	6990	5240	14,000	14,000		14,000	14,000
SOLID WASTE (CU FT/YR)			13,810				120-180	30-36	7-38	7-38	8-38		90-120	90-120
NUISANCE - ODOR	Potential	Potential				None	None	None	None	Potential	Potential		Potential	Potential
NOISE								Above Average						
TRAFFIC				.54		.88	.18	.18	.13	.35	.35		.35	Negligible
SAFETY (INJURIES/10⁶ MAN-HRS)						28.5								
COSTS - CAPITAL ($ x 10⁶)	2.21	1.9-2	2	.043		.85-1.2	1-1.3	1.2-1.3	1.8-2.1	.57-.64	.30-.40		.69-.85	1.1-1.3
RUNNING TOTAL CAPITAL ($ x 10⁶)	2.21	4.11-4.21	6.1-6.2	6.2-6.3		7.1-7.5	8.1-8.8	8.3-8.8	8.9-9.6	7.7-8.1	7.4-7.9		7.8-8.4	8.2-8.8
LAND ($)		19,000	10,000			22-26x10³	4100-5500	4100-5500	2700-3700	13,700-15,400	.6-2.6x10⁵		8200-11,200	340-500
RUNNING GRAND TOTAL ($ x 10⁶)	2.21	4.13-4.23	6.1-6.2	6.2-6.3		7.1-7.5	8.1-8.8	8.3-8.8	8.9-9.6	7.7-8.2	7.5-8.2		7.8-8.4	8.2-8.8
OPERATING (¢/1000 GAL)	4.0	3.4	7.7	.9		3.7-4.9	4.6-7.0	3.15-4.85	3.8-5.3	3.1-4.1	2.6-2.9		3.2-5.4	3.0-5.2
10% AMORTIZED (¢/1000 GAL)	7.1	6.1-6.4	6.5	.1		2.8-3.9	3.2-4.2	3.9-4.2	5.8-6.8	1.8-2.1	1.1-2.1		2.2-2.7	3.5-4.2
TOTAL OPERATING (¢/1000 GAL)	11.1	9.5-9.8	14.2	1		6.5-8.8	7.8-11.2	7.1-9.1	9.6-12.1	4.9-6.2	3.7-5.0		5.4-8.1	6.5-9.4
RUNNING TOTAL (¢/1000 GAL)	11.1	20.6-20.9	34.8-35.1	35.8-36.1		42.3-44.9	50.1-56.1	49.4-54.0	51.9-57.0	47.2-50.1	46.0-49.9		47.7-53.0	48.8-54.3

Activated Sludge-Coagulation-Filtration with
Centrifugation-Incineration of Chemical Sludge - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 8 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	12	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION		FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
		Activated Sludge	Coagulation Filtration	Surface Water	DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270 kwh	3734 kwh	5480 kwh			5905 kwh 404x10⁶ Btu	1810 kwh 100x10⁶ Btu	1510 kwh 120x10⁶ Btu	1460 kwh 44x10⁶ Btu	220 kwh	220 kwh	Not Practical	1260 kwh	1260 kwh
CONCRETE (CU YDS)	756	2100	760	252		45	30	28	34	1210	1210		1220	1220
STEEL (TONS)	75	290	225	16.7		53	55	56	20	120	120		125	125
CHEMICALS (LBS/DAY)			Lime-6300 CO2-26,500	Polymers-21 Cl2-420			192-268	45-55	11-58	11-58	12-58		132-188	132-188
LAND (ACRES)		19	10			12-16	4.1-5.5	4.1-5.5	2.7-3.7	13.7-15.4	60-260		8.2-11.2	.34-.5
LABOR (MAN YRS/YR)	3.2	7.9	4.3			11-14.8	5.6-7.5	4.1-5.8	4.3-6.3	3.4-7.9	10.2-13.9		4.1-4.8	4.8-5.5
OUTPUTS - BOD (MG/L)	130	10-30	3											
(LBS/DAY)	10,400	830-2500	252											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	6400	830-2500	25											
NUTRIENTS: P (MG/L)	14.3	10	.1											
(LBS/DAY)	1140	840	8.4			1600-2300	500-700	500-700	500-700	500-700	500-700		500-700	500-700
N (MG/L)	32	25	17											
(LBS/DAY)	2560	2100	1428							800-1000	800-1000		800-1000	800-1000
HEAVY METALS (LBS/DAY)		25-500	Negligible			25-500	13-326	13-326	13-326	15-330	15-330		15-330	15-330
ATMOSPHERIC EMISSIONS (LBS/DAY)							SO_2=4.4-6.7 NO_x=25-39	HCl=.8-1.2 Particulates=44-70	Metals=2.5-4					
SLUDGES % SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	10,800	12,500	77,400			20,600	6990	6990	5240	14,000	14,000		14,000	14,000
SOLID WASTE (CU FT/YR)			153				120-180	30-36	7-38	7-38	8-38		90-120	90-120
NUISANCE ODOR	Potential	Potential				None	None	None	None	Potential	Potential		Potential	Potential
NOISE								Above Average						
TRAFFIC				.17		.5	.18	.18	.13	.35	.35		.35	Negligible
SAFETY (INJURIES/10⁶ MAN-HRS)						28.5								
COSTS CAPITAL ($ x 10⁶)	2.21	1.9-2	2	.063		1.7-2.3	1-1.3	1.2-1.3	1.8-2.1	.57-.64	.30-.40		.69-.85	1.1-1.3
RUNNING TOTAL CAPITAL ($ x 10⁶)	2.21	4.11-4.21	6.1-6.2	6.2-6.3		7.9-8.6	8.9-9.9	9.1-9.9	9.7-10.7	8.5-9.2	8.2-9		8.6-9.5	9-9.9
LAND ($)		19,000	10,000			12-16x10³	4100-5500	4100-5500	2700-3700	13,700-15,400	.6-2.6x10⁵		8,450-11,200	340-500
RUNNING GRAND TOTAL ($ x 10⁶)	2.21	4.13-4.23	6.1-6.2	6.2-6.3		7.9-8.6	8.9-9.9	9.1-9.9	9.7-10.7	8.5-9.3	8.3-9.3		8.6-9.5	9-9.9
OPERATING (¢/1000 GAL)	4	3.4	7.7	.9		5-8.7	4.6-7.0	3.15-4.85	3.8-5.3	3.1-4.1	2.6-2.9		3.2-5.4	3.0-5.2
10% AMORTIZED (¢/1000 GAL)	7.1	6.1-6.4	6.5	.1		5.5-7.5	3.2-4.2	3.9-4.2	5.8-6.8	1.8-2.1	1.1-2.1		2.2-2.7	3.5-4.2
TOTAL OPERATING (¢/1000 GAL)	11.1	9.5-9.8	14.2	1.0		11.3-16.2	7.8-11.2	7.1-9.1	9.6-12.1	4.9-6.2	3.7-5.0		5.4-8.1	6.5-9.4
RUNNING TOTAL (¢/1000 GAL)	11.1	20.6-20.9	34.8-35.1	35.8-36.1		47.1-52.3	54.9-63.5	54.2-61.4	56.7-64.4	52.0-58.5	50.8-57.3		52.5-60.4	53.6-61.7

Activated Sludge-Coagulation-Filtration with Centrifugation-Recalcination of Chemical Sludge - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 8 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Coagulation Filtration	LIQUID DISPOSAL Surface Water	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	9 GRAVITY VACUUM FILTRATION INCINERATION LANDFILL	1 FLOTATION CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 FLOTATION PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 FLOTATION DIGESTION SAND DRYING LANDFILL	5 FLOTATION DIGESTION LAND SPREADING	6 FLOTATION DIGESTION OCEAN DUMPING	7 FLOTATION DIGESTION VACUUM FILTRATION LANDFILL	8 FLOTATION DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	4300 kwh	11,900 kwh	16,000 kwh			3.1x10^4 kwh 2.7x10^9 Btu	18,100 kwh 1x10^9 Btu	15,100 kwh 1.2x10^9 Btu	14,600 kwh 420x10^6 Btu	2200 kwh	2200 kwh	2200 kwh	12,600 kwh	12,600 kwh
CONCRETE (CU YDS)	6240	14,000	9300	2120		370	365	342	373	10,500	10,500	10,500	10,500	10,500
STEEL (TONS)	545	1600	710	140		400	300	295	340	960	960	960	1000	1000
CHEMICALS (LBS/DAY)			Polymer-210 Lime-310,000	CO_2-265,000 Cl_2-4200			1917-2683	450-550	117-583	117-583	117-583	117-583	1317-1880	1317-1880
LAND (ACRES)		38	25			196-266	41-55	41-55	27-37	137-154	603-2603	2.6-3.6	82-112	3-4
LABOR (MAN YRS/YR)	28	41	29			61-83	38.4-49.2	26.7-35.4	31-36	20-40	13.6-18.4	13.6-18.4	25-29	25-28
OUTPUTS - BOD (MG/L)	130	10-30	3											
(LBS/DAY)	1.04x10^5	.8-3x10^4	2520											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	64,000	.8-3x10^4	250											
NUTRIENTS: P (MG/L)	14.3	10	.1											
(LBS/DAY)	11,400	8400	84			8000-11,500	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000
N (MG/L)	32	25	17											
(LBS/DAY)	25,600	21,000	14,280							8000-10,000	8000-10,000	8000-10,000	8000-10,000	8000-10,000
HEAVY METALS (LBS/DAY)		250-5000	Negligible			250-5000	125-3260	125-3260	125-3260	150-3300	150-3300	150-3300	150-3300	150-3300
ATMOSPHERIC EMISSIONS (LBS/DAY)							SO_2=44-67 NO_x=250-390	SO_2=44-67 Metals=25-40	Particulates= 440-700					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	108,000	125,000	441,000			353,000	69,900	69,900	52,400	140,000	140,000	140,000	140,000	140,000
SOLID WASTE (CU FT/YR)			1.4x10^5				1200-1800	300-360	80-380	80-380	80-380		900-1200	900-1200
NUISANCE - ODOR	Potential	Potential				None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE								Above Average						
TRAFFIC				5.-		8.8	1.75	1.75	1.1	3.2	[illegible]	.03	3.3	.1
SAFETY (INJURIES/10^6 MAN-HRS)				-		41								
COSTS - CAPITAL ($ x 10^6)	11.7	14-15	10.2	1		5.2-6.9	3.4-4.7	5-6.8	11-15	4.4-5.2	5.1-6.9	14.7-19.9	3.7-4.9	3.5-4.7
RUNNING TOTAL CAPITAL ($ x 10^6)	11.7	25.7-26.7	35.9-36.9	36-37		41.2-43.9	44.6-48.6	46.2-50.7	52.2-56.9	45.6-49.1	46.3-50.8	55.9-63.8	44.9-48.8	44.7-48.6
LAND ($)		38,000	25,000			196-266x10^3	41,000-55,000	41,000-55,000	27,000-37,000	1.32-1.56 x10^6	.6-2.6x10^6	2600-3600	.82-1.1x10^6	3000-4000
RUNNING GRAND TOTAL ($ x 10^6)	11.7	25.7-26.7	35.9-36.9	36-37		41.4-44.2	44.8-49	46.4-51.1	52.4-59.2	45.9-49.6	47.1-53.7	56.1-64.1	45.2-49.2	44.9-48.9
OPERATING (¢/1000 GAL)	2.6	1.2	5.3	.7		4-6.8	4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	2.2-2.8	.54-.73	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.8	4.5-4.8	3.3	.04		1.8-2.3	1.1-1.5	1.6-2.2	3.6-4.8	1.4-1.7	1.8-3.1	4.7-6.4	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	6.4	5.7-6	8.6	.7		5.8-9.1	5.5-8.4	4.6-6.9	7.2-9.9	4.5-5.8	4.0-5.9	5.2-7.1	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	6.4	12.1-12.5	20.7-21.0	21.4-21.9		27.2-30.8	32.7-39.2	31.8-37.7	34.4-40.7	31.7-35.6	31.2-36.7	32.4-37.9	31.6-37.7	31.1-37.3

Activated Sludge-Coagulation-Filtration with Filtration-Incineration of Chemical Sludge - 100 MGD

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PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 8 AT A FLOW RATE OF 100 MGD.

	LIQUID TREATMENT				CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Coagulation Filtration	LIQUID DISPOSAL Surface Water	10	1	2	3	4	5	6	7	8
UNIT OPERATION THICKENING:					GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
CONDITIONING:						CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
DEWATERING:					VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
DISPOSAL:					RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	4000 kwh	11,900 kwh	16,000 kwh		8.1×10^4 kwh 4.6×10^9 Btu	18,100 kwh 1×10^9 Btu	15,100 kwh 1.2×10^9 Btu	14,600 kwh 470×10^6 Btu	2200 kwh	2200 kwh	2200 kwh	12,600 kwh	12,600 kwh
CONCRETE (CU YDS)	6240	14,000	9300	2120	518	365	342	373	10,500	10,500	10,500	10,500	10,500
STEEL (TONS)	545	1600	710	140	560	300	295	340	960	960	960	1000	1000
CHEMICALS (LBS/DAY)			Polymer-210 Lime-63,000	CO_2-265,000 Cl_2-4200		1917-2683	450-550	117-583	117-583	112-583	112-583	1317-1880	1317-1880
LAND (ACRES)		38	25		120-162	41-55	41-55	27-37	137-154	603-2603	2.6-3.6	82-112	3-4
LABOR (MAN YRS/YR)	28	41	29		91-126	38.4-49.2	26.7-35.4	31-36	20-60	13.6-18.4	13.6-18.4	25-29	25-28
OUTPUTS - BOD (MG/L)	130	10-30	3										
(LBS/DAY)	1.04×10^5	$8-3 \times 10^4$	2520										
SUSPENDED SOLIDS (MG/L)	80	10-30	.3										
(LBS/DAY)	64,000	$8-3 \times 10^4$	250										
NUTRIENTS: P (MG/L)	14.3	10	.1										
(LBS/DAY)	11,400	8600	86		$16-23 \times 10^3$	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000
N (MG/L)	32	25	17										
(LBS/DAY)	25,600	21,000	14,280						8000-10,000	8000-10,000	8000-10,000	8000-10,000	8000-10,000
HEAVY METALS (LBS/DAY)		250-5000	Negligible		250-5000	125-3260	125-3260	125-3260	150-3300	150-3300	150-3300	150-3300	150-3300
ATMOSPHERIC EMISSIONS (LBS/DAY)						SO_2=44-67 NO_x=250-390	HCl=8-12 Particulates=440-700	Metals=25-40					
SLUDGES-% SOLIDS	5	1	1-5		100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	108,000	125,000	774,000		206,000	69,900	69,900	52,400	140,000	140,000	140,000	140,000	140,000
SOLID WASTE (CU YT/YR)			61,530			1200-1800	300-360	80-380	80-380	80-380		900-1200	900-1200
NUISANCE - ODOR	Potential	Potential			None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE							Above Average						
TRAFFIC				1.7	5	1.75	1.75	1.3	3.5	3.5	.03	3.5	.1
SAFETY (INJURIES/10^6 MAN-HRS)					41								
COSTS - CAPITAL ($\$ \times 10^6$)	11.7	14-15	10.2	.11	9.7-13.2	3.4-4.7	5-6.8	11-15	4.4-5.2	5.1-6.9	14.7-19.9	3.7-4.9	3.5-4.7
RUNNING TOTAL CAPITAL ($\$ \times 10^6$)	11.7	25.7-26.7	35.9-36.9	36-37	45.7-50.2	49.1-54.9	50.7-57	56.7-65.2	50.1-55.4	50.8-57.1	60.4-70.1	49.4-55.1	49.2-54.9
LAND ($)		38,000	25,000		$1.2-1.62 \times 10^5$	41,000-54,000	41,000-55,000	27,000-37,000	$1.37-1.54 \times 10^5$	$.6-2.6 \times 10^6$	2600-3600	$.82-1.1 \times 10^5$	3000-4000
RUNNING GRAND TOTAL ($\$ \times 10^6$)	11.7	25.7-26.7	35.9-36.9	36-37	45.8-50.4	49.2-55.2	50.8-57.3	56.8-65.4	50.3-55.8	51.5-59.9	60.5-70.3	49.5-55.2	49.3-55.1
OPERATING (¢/1000 GAL)	2.6	1.2	5.3	.7	4.8-11.1	4.4-6.9	2.95-4.65	3.8-5.1	[illegible]	[illegible]	.54-.73	[illegible]	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.8	4.5-4.8	3.3	.04	3.2-4.3	[illegible]	[illegible]	3.9-4.8	[illegible]	1.8-3.1	[illegible]	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	6.4	5.7-6	8.6	.7	8-15.4	[illegible]	[illegible]	7.2-9.4	[illegible]	4.0-5.9	5.2-7.1	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	6.4	12.1-12.6	20.7-21.0	21.4-21.7	29.4-37.1	34.9-43.5	34-44	35.6-47	33.9-42.9	33.4-43	34.6-44.2	33.8-44	33.3-43.6

Activated Sludge-Coagulation-Filtration with
Filtration-Recalcination of Chemical Sludge - 100 MGD

Reproduced from best available copy.

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 8 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Coagulation Filtration	LIQUID DISPOSAL Surface Water	UNIT OPERATION	11	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	4000 kwh	11,900 kwh	16,000 kwh			1.7x10^4 kwh 1.7x10^9 Btu	18,100 kwh 1x10^9 Btu	15,100 kwh 1.2x10^9 Btu	14,600 kwh 470x10^6 Btu	2200 kwh	2200 kwh	2200 kwh	12,600 kwh	12,600 kwh
CONCRETE (CU YDS)	6240	14,000	8300	2120		320	365	342	373	10,500	10,500	10,500	10,500	10,500
STEEL (TONS)	545	1600	710	140		270	300	295	340	960	960	960	1000	1000
CHEMICALS (LBS/DAY)			Polymer-210 Lime-210,000	CO_2-205,000 Cl_2-6200			1917-2683	450-550	117-583	117-583	117-583	117-583	1317-1880	1317-1880
LAND (ACRES)		38	25			196-266	41-55	41-55	27-37	137-154	603-2603	2.6-3.6	82-112	3-4
LABOR (MAN YRS/YR)	28	41	29			56-72	38.4-49.2	26.7-35.4	31-36	20-60	13.6-18.4	13.6-18.4	25-29	25-28
OUTPUTS - BOD (MG/L)	130	10-30	3											
(LBS/DAY)	1.04x10^5	8-3x10^4	250											
SUSPENDED SOLIDS (MG/L)	80	10-30	3											
(LBS/DAY)	64,000	8-3x10^4	2520											
NUTRIENTS: P (MG/L)	14.3	10	.1											
(LBS/DAY)	11,400	8400	84			8000-11,500	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000
N (MG/L)	32	25	17											
(LBS/DAY)	25,600	21,000	14,280							8000-10,000	8000-10,000	8000-10,000	8000-10,000	8000-10,000
HEAVY METALS (LBS/DAY)		250-5000	Negligible			250-5000	125-3260	125-3260	125-3260	150-3300	150-3300	150-3300	150-3300	150-3300
ATMOSPHERIC EMISSIONS (LBS/DAY)							SO_2=44-67 Metals=25-40	HCl=8-12 NO_x=250-390	Particulates=440-700					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	108,000	125,000	461,000			353,000	69,900	69,900	52,400	140,000	140,000	140,000	140,000	140,000
SOLID WASTE (CU FT/YR)			1.6x10^5				1200-1800	300-360	80-380	80-380	80-380		900-1200	900-1200
NUISANCE - ODOR	Potential	Potential				None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE								Above Average						
TRAFFIC				5.4		8.8	1.75	1.75	1.3	3.5	3.5	.03	3.5	.1
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($ x 10^6)	11.7	14-15	10.2	.13		3.6-4.9	3.4-4.7	5-6.8	11-15	4.4-5.2	5.1-6.9	14.7-19.9	3.7-4.9	3.5-4.7
RUNNING TOTAL CAPITAL ($ x 10^6)	11.7	25.7-26.7	35.9-36.9	36-37		39.6-41.9	43-46.6	44.6-48.7	50.6-56.9	44-47.1	44.7-48.8	54.3-61.8	43.3-46.8	43.1-46.6
LAND ($)		38,000	25,000			.196-266x10^3	41,000-55,000	41,000-55,000	27,000-37,000	1.37-1.54 x10^5	.6-2.6x10^6	2600-3600	.82-1.1x10	3000-4000
RUNNING GRAND TOTAL ($ x 10^6)	11.7	25.7-26.7	35.9-36.9	36-37		39.8-42.2	43.2-47	44.8-49.1	50.8-57.2	44.3-47.6	45.5-51.7	54.5-62.1	43.6-47.2	43.3-46.9
OPERATING (¢/1000 GAL)	2.6	1.2	5.3	.7		3.4-4.6	4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	2.2-2.8	.54-.73	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.8	4.5-4.8	3.3	.04		1.2-1.7	1.1-1.5	1.6-2.2	3.6-4.8	1.4-1.7	1.8-3.1	4.7-6.4	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	6.4	5.7-6	8.6	.7		4.6-6.3	5.5-8.4	4.6-6.9	7.2-9.9	4.5-5.8	4.0-5.9	5.2-7.1	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	6.4	12.1-12.4	20.7-21.0	21.6-21.7		26.0-28.0	31.5-36.4	30.6-34.9	33.2-37.9	30.5-33.8	30.8-33.9	31.2-35.1	30.4-34.9	29.9-34.5

Activated Sludge-Coagulation-Filtration with Centrifugation-Incineration of Chemical Sludge - 100 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 8 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Coagulation Filtration	LIQUID DISPOSAL Surface Water	UNIT OPERATION	12	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	4000 kwh	11,900 kwh	16,000 kwh			5.9x10^3 kwh 2.6x10^9 Btu	18,100 kwh 1x10^9 Btu	15,100 kwh 1.2x10^9 Btu	14,600 kwh 470x10^6 Btu	2200 kwh	2200 kwh	2200 kwh	12,600 kwh	12,600 kwh
CONCRETE (CU YDS)	6240	14,000	8300	2120		448	365	342	373	10,500	10,500	10,500	10,500	10,500
STEEL (TONS)	545	1600	710	140		378	300	235	340	960	960	960	1000	1000
CHEMICALS (LBS/DAY)			Polymer-210 Lime-63,000	CO_2-265,000 Cl_2-4200			1917-2683	450-550	117-583	117-583	117-583	117-583	1317-1880	1317-1880
LAND (ACRES)		38	25			120-160	41-55	41-55	27-37	137-154	603-2603	2.6-3.6	82-112	3-4
LABOR (MAN YRS/YR)	28	41	29			85-115	38.4-49.2	26.7-35.4	31-36	20-60	13.6-18.4	13.6-18.4	25-29	25-28
OUTPUTS - BOD (MG/L)	130	10-30	3											
(LBS/DAY)	1.04x10^5	.8-3x10^4	2520											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	64,000	.8-3x10^4	250											
NUTRIENTS: P (MG/L)	14.3	10	.1											
(LBS/DAY)	11,400	8400	84			16-23x10^3	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000
N (MG/L)	32	25	17											
(LBS/DAY)	25,600	21,000	14,280							8000-10,000	8000-10,000	8000-10,000	8000-10,000	8000-10,000
HEAVY METALS (LBS/DAY)		250-5000	Negligible			250-5000	125-3260	125-3260	125-3260	150-3300	150-3300	150-3300	150-3300	150-3300
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=25-40 NO_x=250-390	SO_2=44-67 Particulates=440-700	HCl=8-12					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	108,000	125,000	774,000			206,000	69,900	69,900	52,400	140,000	140,000	140,000	140,000	140,000
SOLID WASTE (CU FT/YR)			41,530				1200-1800	300-360	80-380	80-380	80-380		900-1200	900-1200
NUISANCE - ODOR	Potential	Potential				None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE								Above Average						
TRAFFIC				1.7		5	1.75	1.75	1.1	1.2	1.2	.03	2.5	.1
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($ x 10^6)	11.7	14-15	10.2	.13		7.3-9.9	3.4-4.7	5-6.8	11-15	4.4-5.2	5.1-6.1	14.7-19.9	3.7-4.9	3.5-4.7
RUNNING TOTAL CAPITAL ($ x 10^6)	11.7	25.7-26.2	35.9-36.9	36-37		43.3-46.9	46.7-51.6	48.3-53.7	54.3-61.9	47.7-52.1	48.4-53	58-66.8	47-51.8	46.8-51.6
LAND ($)		38,000	25,000			45-115x10^3	41,000-55,000	41,000-55,000	27,000-37,000	1.37-1.54 x10^5	.6-2.6x10^6	2600-3600	.82-1.1x10^5	3000-4000
RUNNING GRAND TOTAL ($ x 10^6)	11.7	25.7-26.7	35.9-36.9	36-37		43.4-47	46.8-51.8	48.4-53.9	54.4-62	47.9-52.4	49.1-55.7	58.1-66.9	47.2-52	46.9-51.7
OPERATING (¢/1000 GAL)	2.6	1.2	[illegible]	[illegible]		5.3-9	4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	2.2-2.8	.54-.73	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.8	4.5-4.8	[illegible]	.04		2.4-3.2	1.1-1.5	1.6-2.2	3.6-4.8	1.4-1.7	1.8-3.1	4.7-6.4	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	6.4	5.7-6	8.6	.7		7.7-12.2	5.5-8.4	4.6-6.9	7.2-9.9	4.5-5.8	4.0-5.9	5.2-7.1	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	6.4	12.1-12.4	20.7-21.0	21.4-21.7		29.1-33.9	34.6-42.3	33.7-40.8	36.3-43.8	33.6-39.7	33.1-39.8	34.3-41	33.5-40.8	33-40.4

Activated Sludge-Coagulation-Filtration with
Centrifugation-Recalcination of Chemical Sludge - 100 MGD

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PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 8 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Coagulation Filtration	LIQUID DISPOSAL Surface Water	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	9 GRAVITY VACUUM FILTRATION INCINERATION LANDFILL	1 FLOTATION CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 FLOTATION PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 FLOTATION DIGESTION SAND DRYING LANDFILL	5 FLOTATION DIGESTION LAND SPREADING	6 FLOTATION DIGESTION OCEAN DUMPING	7 FLOTATION DIGESTION VACUUM FILTRATION LANDFILL	8 FLOTATION DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	40,000 kwh	1.19x 10^5 kwh	1.16x 10^5 kwh			31x 10^4 kwh 27x 10^9 Btu	1.8x 10^5 kwh 10x 10^9 Btu	1.5x 10^5 kwh 12x 10^9 Btu	1.5x 10^5 kwh 4.7x 10^9 Btu	22,000 kwh	22,000 kwh	22,000 kwh	1.3x 10^5 kwh	1.3x 10^5 kwh
CONCRETE (CU YDS)	61,600	166,000	76,000	19,300		3600	3520	3600	3560	105,000	105,000	105,000	105,000	105,000
STEEL (TONS)	5600	17,400	6500	1270		3900	2860	2780	3040	9600	9600	9600	10,000	10,000
CHEMICALS (LBS/DAY)			Polymer-2100 Lime-2.1x 10^6	CO_2-7.96x 10^5 Cl_2-42,000			19,170-26,830	4500-5500	1170-5830	1170-5830	1170-5830	1170-5830	13,170-18,800	13,170-18,800
LAND (ACRES)		190	80			1960-2660	410-550	410-550	270-370	1370-1560	6000-27,000	26-36	820-1120	30-40
LABOR (MAN YRS/YR)	280	410	290			610-830	384-492	267-354	310-360	200-600	132-178	131-178	250-290	250-280
OUTPUTS - BOD (MG/L)	130	10-30	3											
(LBS/DAY)	1.04x 10^6	.8-3x 10^5	25,200											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	6.6x 10^5	.8-3x 10^5	2500											
NUTRIENTS P (MG/L)	14.3	10	.1											
(LBS/DAY)	114,000	84,000	840			8-11.5x 10^4	5-7 x 10^4	5-7 x 10^4	5-7 x 10^4	5-7x 10^4	5-7x 10^4	5-7x 10^4	5-7x 10^4	5-7x 10^4
N (MG/L)	32	25	17											
(LBS/DAY)	2.56x 10^5	2.1x 10^5	142,800							.8-1x 10^5	.8-1x 10^5	.8-1x 10^5	.8-1x 10^5	.8-1x 10^5
HEAVY METALS (LBS/DAY)		2500-50,000		2500-50,000		2500-50,000	.13-3.3x 10^4	.13-3.3x 10^4	.13-3.3x 10^4	.15-3.3x 10^4	.15-3.3x 10^4	.15-3.3x 10^4	.15-3.3x 10^4	.15-3.3x 10^4
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=250-400 SO_2=440-670 HCl=80-120 NO_x=2500-3900 Particulates=4400-7000							
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	1.08x 10^6	1.25x 10^6	4.61x 10^5			3.53x 10^6	699,000	699,000	523,000	1.4x 10^6	1.4x 10^6	1.4x 10^6	1.4x 10^6	[illegible]
SOLID WASTE (CU YT/YR)			1.8x [illegible]				12-18x 10^3	3000-3600	920-1800	900-1800	920-1800		9-12x 10^3	9-12x 10^3
NUISANCE - ODOR	Potential	Potential				None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE								Above Average						
TRAFFIC				54		88	17.2	17.2	13.1	16	[illegible]	.3	33	1
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($ x 10^6)	117	143-150	102	1.3		52-69	34-47	50-68	110-150	[illegible]	7.1-9.7	16.1-21.8	36-48	35-47
RUNNING TOTAL CAPITAL ($ x 10^6)	117	260-261	362-369	363-370		415-439	449-486	465-507	525-599	419-491	432-449	431-461	451-417	450-486
LAND ($)		190,000	80,000			1.96-2.66x 10^6	4.1-5.5x 10^5	[illegible]	2.0-3.7x 10^5	[illegible]	6-27x 10^6	2.6-3.6x 10^4	.82-11x 10^6	3-4x 10^4
RUNNING GRAND TOTAL ($ x 10^6)	117	260-261	362-369	363-370		417-442	451-490	467-511	527-592	[illegible]-498	410-479	433-464	454-501	452-489
OPERATING (¢/1000 GAL)	2.0	1.9	5.3	[illegible]		4-6.8	4.4-6.9	2.95-4.65	3.6-5.1	[illegible]	1.7-2.4	.22-.3	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.7	4.6-4.8	3.3	.04		1.8-2.3	1.1-1.5	1.6-2.2	3.6-4.8	1.5-2.7	[illegible]	.52-.7	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	5.7	5.6-5.8	8.6	.5		5.8-9.1	5.5-8.4	4.6-6.9	7.2-9.9	4.6-5.[illegible]	[illegible]	.7-1.0	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	5.7	11.3-11.5	19.9-20.1	20.5-20.6		26.2-29.7	31.7-38.1	30.8-36.6	33.4-39.6	30.8-35.5	26.3-33.3	26.9-30.7	30.6-36.6	30.1-36.2

Activated Sludge-Coagulation-Filtration with Filtration-Incineration of Chemical Sludge - 1000 MGD

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PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 8 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Coagulation Filtration	LIQUID DISPOSAL Surface Water	UNIT OPERATION	10	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	40,000 kwh	$1.19x10^5$ kwh	$1.16x10^5$ kwh			$81x10^8$ kwh $46x10^9$ Btu	$1.8x10^5$ kwh $10x10^9$ Btu	$1.5x10^5$ kwh $12x10^9$ Btu	$1.5x10^5$ kwh $4.7x10^9$ Btu	22,000 kwh	22,000 kwh	22,000 kwh	$1.3x10^5$ kwh	$1.3x10^5$ kwh
CONCRETE (CU YDS)	61,600	166,000	76,000	19,300		5000	3520	3600	3560	105,000	105,000	105,000	105,000	105,000
STEEL (TONS)	5400	17,400	6500	1270		5400	2860	2780	3040	9600	9600	9600	10,000	10,000
CHEMICALS (LBS/DAY)			Lime-$6.3x10^5$ CO_2-$7.95x10^5$	Polymer-2100 Cl_2-42,000			19,170-26,830	4500-5500	1170-5830	1170-5830	1170-5830	1170-5830	13,170-18,800	13,170-18,800
LAND (ACRES)		190	80			1200-1620	410-550	410-550	270-370	1370-1540	6000-27,000	26-36	820-1120	30-40
LABOR (MAN YRS/YR)	280	410	290			908-1256	384-492	267-354	310-360	200-600	132-178	131-178	250-290	250-280
OUTPUTS - BOD (MG/L)	130	10-30	3											
(LBS/DAY)	$1.04x10^6$	$.8-3x10^5$	25,200											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	$6.6x10^5$	$.8-3x10^5$	2500											
NUTRIENTS: P (MG/L)	14.3	10	.1											
(LBS/DAY)	114,000	84,000	840			$16-23x10^4$	$5-7\ x10^4$	$5-7\ x10^4$	$5-7\ x10^4$	$5-7x10^4$	$5-7x10^4$	$5-7x10^4$	$5-7x10^4$	$5-7x10^4$
N (MG/L)	32	25	17											
(LBS/DAY)	$2.56x10^5$	$2.1x10^5$	142,800							$.8-1x10^5$	$.8-1x10^5$	$.8-1x10^5$	$.8-1x10^5$	$.8-1x10^5$
HEAVY METALS (LBS/DAY)		2500-50,000		2500-50,000		2500-50,000	$.13-3.3x10^4$	$.13-3.3x10^4$	$.13-3.3x10^4$	$.15-3.3x10^4$	$.15-3.3x10^4$	$.15-3.3x10^4$	$.15-3.3x10^4$	$.15-3.3x10^4$
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=250-400 SO_2=440-670 HCl=60-120 NO_x=2500-3900 Particulates=4400-7000							
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	$1.08x10^6$	$1.25x10^6$	$7.74x10^6$			$2.06x10^6$	699,000	699,000	524,000	$1.4x10^6$	$1.4x10^6$	$1.4x10^6$	$1.4x10^6$	$1.4x10^6$
SOLID WASTE (CU FT/YR)			$4.15x10^5$				$12-18x10^3$	3000-3600	800-3800	800-3800	800-3800		$9-12x10^3$	$9-12x10^3$
NUISANCE - ODOR	Potential	Potential				None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE								Above Average						
TRAFFIC				17		50	17.5	17.5	13.1	35	35	.3	35	1
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($\$ \times 10^6$)	117	143-150	102	1.3		97-132	34-47	50-68	110-150	44-52	7.1-9.7	16.1-21.8	36-48	35-47
RUNNING TOTAL CAPITAL ($\$ \times 10^6$)	117	260-267	362-369	363-370		460-502	494-549	510-570	570-652	504-554	467-512	476-524	496-550	495-549
LAND ($)		190,000	80,000			$1.2-1.6x10^6$	$4.1-5.5x10^5$	$4.1-5.5x10^5$	$2.7-3.7x10^5$	$1.37-1.54x10^6$	$6-27x10^6$	26,000-36,000	$.82-1.1x10^6$	30,000-40,000
RUNNING GRAND TOTAL ($\$ \times 10^6$)	117	260-267	362-369	363-370		461-504	495-552	511-573	571-654	506-558	474-541	477-526	498-553	496-551
OPERATING (¢/1000 GAL)	2.0	1.0	5.3	.5		4.8-11.1	4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	1.7-2.4	.22-.3	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.7	4.6-4.8	3.3	.04		3.2-4.3	1.1-1.5	1.6-2.2	3.6-4.8	1.5-1.7	.4-1.2	.52-.7	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	5.7	5.6-5.8	8.6	.5		8-15.4	5.5-8.4	4.6-6.9	7.2-9.9	4.6-5.8	2.1-3.6	.7-1.0	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	5.7	11.1-11.5	19.9-20.1	20.4-20.6		28.4-36	33.9-44.4	33-42.9	35.6-45.9	33-41.8	30.5-39.6	29.1-37	32.8-45.9	32.3-42.5

Activated Sludge-Coagulation-Filtration with
Filtration-Recalcination of Chemical Sludge - 1000 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 8 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Coagulation Filtration	LIQUID DISPOSAL Surface Water	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	11 GRAVITY CENTRIFUGE INCINERATION LANDFILL	1 FLOTATION CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 FLOTATION PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 FLOTATION DIGESTION SAND DRYING LANDFILL	5 FLOTATION DIGESTION LAND SPREADING	6 FLOTATION DIGESTION OCEAN DUMPING	7 FLOTATION DIGESTION VACUUM FILTRATION LANDFILL	8 FLOTATION DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	30,000 kwh	1.19 x 10^5 kwh	1.6 x 10^5 kwh			$17x10^3$ kwh $27x10^9$ Btu	$1.8x10^5$ kwh $10x10^9$ Btu	$1.5x10^5$ kwh $12x10^9$ Btu	$1.5x10^5$ kwh $4.7x10^9$ Btu	22,000 kwh	22,000 kwh	22,000 kwh	$1.3x10^5$ kwh	$1.3x10^5$ kwh
CONCRETE (CU YDS)	61,600	166,000	76,000	19,300		3100	3520	3400	3560	105,000	105,000	105,000	105,000	105,000
STEEL (TONS)	5400	17,400	6500	1270		2600	2860	2780	3040	9600	9600	9600	10,000	10,000
CHEMICALS (LBS/DAY)			Polymer-2100 Lime-$2.2x10^6$	CO_2-$7.95x10^5$ Cl_2-42,000			19,170-26,830	4500-5500	1170-5830	1170-5830	1170-5830	1170-5830	13,170-18,800	13,170-18,800
LAND (ACRES)		190	80			1960-2660	410-550	410-550	270-370	1370-1540	6000-27,000	26-36	820-1120	30-40
LABOR (MAN HRS/YR)	280	410	290			540-720	384-492	267-354	310-360	200-600	132-178	131-178	250-290	250-280
OUTPUTS - BOD (MG/L)	130	10-30	3											
(LBS/DAY)	$1.04x10^6$	.8-$3x10^5$	25,200											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	$6.4x10^5$	.8-$3x10^5$	2500											
NUTRIENTS P (MG/L)	14.1	10	.1											
(LBS/DAY)	114,000	84,000	840			8-$11.5x10^4$	5-7 $x10^4$	5-7 $x10^4$	5-7 $x10^4$	5-$7x10^4$	5-$7x10^4$	5-$7x10^4$	5-$7x10^4$	5-$7x10^4$
N (MG/L)	32	25	17											
(LBS/DAY)	$2.56x10^5$	$2.1x10^5$	142,000							.8-$1x10^5$	.8-$1x10^5$	.8-$1x10^5$	.8-$1x10^5$	.8-$1x10^5$
HEAVY METALS (LBS/DAY)		2500-50,000		2500-50,000		2500-50,000	.13-$3.3x10^4$	.13-$3.3x10^4$	.13-$3.3x10^4$	.15-$3.3x10^4$	.15-$3.3x10^4$	.15-$3.3x10^4$	.15-$3.3x10^4$	.15-$3.3x10^4$
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=250-400 SO_2=440-670 HCl=80-120 NO_x=2500-3900 Particulates=4400-7000							
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	$1.08x10^6$	$1.25x10^6$	$4.41x10^6$			$3.53x10^6$	699,000	699,000	224,000	$1.4x10^6$	$1.4x10^6$	$1.4x10^6$	$1.4x10^6$	$1.4x10^6$
SOLID WASTE (CU FT YR)			$1.4x10^6$				12-$18x10^3$	3000-3600	800-3800	800-1800	800-3800		9-$12x10^3$	9-$12x10^3$
NUISANCE - ODOR	Potential	Potential				None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE								Above Average						
TRAFFIC				54		88	17.5	17.5	13.1	35	35	.3	35	1
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($ x 10^6)	117	143-150	102	1.3		36-49	34-47	50-68	110-150	44-52	7.1-9.7	16.1-21.8	36-48	35-47
RUNNING TOTAL CAPITAL ($ x 10^6)	117	260-267	362-369	363-370		399-419	433-466	449-487	509-569	443-471	406-429	415-441	435-467	434-466
LAND ($)		190,000	80,000			1.96-2.26 x 10^5	4.1-$5.5x10^5$	4.1-$5.5x10^5$	2.7-$3.7x10^5$	1.37-1.54 x 10^6	6-$27x10^6$	26,000-36,000	.82-1.1x10	30,000-40,000
RUNNING GRAND TOTAL ($ x 10^6)	117	260-267	362-369	363-370		401-421	435-469	451-490	511-571	446-475	414-458	417-443	438-470	436-468
OPERATING (¢/1000 GAL)	2.0	1.0	5.3	.5		3.4-4.6	4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	1.7-2.4	.22-.3	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.7	4.6-4.8	3.3	.04		1.2-1.7	1.1-1.5	1.6-2.2	3.6-4.8	1.5-1.7	.4-1.2	.52-.7	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	5.7	5.6-5.8	8.6	.5		4.6-6.3	5.5-8.4	4.6-6.9	7.2-9.9	4.6-5.8	2.1-3.6	.7-1.0	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	5.7	11.3-11.5	19.9-20.1	20.4-20.6		25-26.9	30.5-35.3	29.6-33.8	32.2-36.8	29.6-32.7	27.1-30.5	25.7-27.9	29.4-33.8	28.9-33.4

Activated Sludge-Coagulation-Filtration with Centrifugation-Incineration of Chemical Sludge - 1000 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 8 AT A FLOW RATE OF 1000 MGD

LIQUID TREATMENT

	PRIMARY	SECONDARY Activated Sludge	TERTIARY Coagulation Filtration	LIQUID DISPOSAL Surface Water
INPUTS - ENERGY (UNITS/DAY)	40,000 kwh	1.9x10^5 kwh	1.6x10^5 kwh	
CONCRETE (CU YDS)	61,600	166,000	76,000	19,300
STEEL (TONS)	5400	17,400	6500	1270
CHEMICALS (LBS/DAY)		Polymer-2100	Lime-6.3x10^5	CO2-7.95x10^5 Cl2-42,000
LAND (ACRES)		190	80	
LABOR (MAN YRS/YR)	280	410	290	
OUTPUTS - BOD (MG/L)	130	10-30	3	
(LBS/DAY)	1.04x10^6	.8-3x10^5	25,200	
SUSPENDED SOLIDS (MG/L)	80	10-30	.3	
(LBS/DAY)	6.3x10^5	.8-3x10^5	2500	
NUTRIENTS. P (MG/L)	14.3	10	.1	
(LBS/DAY)	114,000	84,000	840	
N (MG/L)	32	25	17	
(LBS/DAY)	2.26x10^5	2.1x10^5	142,800	
HEAVY METALS (LBS/DAY)		2500-50,000		2500-50,000
ATMOSPHERIC EMISSIONS (LBS/DAY)				
SLUDGES-% SOLIDS	5	1	1-5	
TOTAL DRY WT. (LBS/DAY)	1.08x10^6	1.25x10^6	7.74x10^6	
SOLID WASTE (CU FT/YR)			4.15x10^5	
NUISANCE - ODOR	Potential	Potential		
NOISE				
TRAFFIC				17
SAFETY (INJURIES/10^6 MAN-HRS)				
COSTS - CAPITAL ($ x 10^6)	117	143-150	102	1.3
RUNNING TOTAL CAPITAL ($ x 10^6)	117	260-267	362-369	363-370
LAND ($)		190,000	80,000	
RUNNING GRAND TOTAL ($ x 10^6)	117	260-267	362-369	363-370
OPERATING (¢/1000 GAL)	2.0	1.0	5.3	.5
10% AMORTIZED (¢/1000 GAL)	3.7	4.6-4.8	3.3	.04
TOTAL OPERATING (¢/1000 GAL)	5.7	5.6-5.8	8.6	.5
RUNNING TOTAL (¢/1000 GAL)	5.7	11.3-11.5	19.9-20.1	20.4-20.6

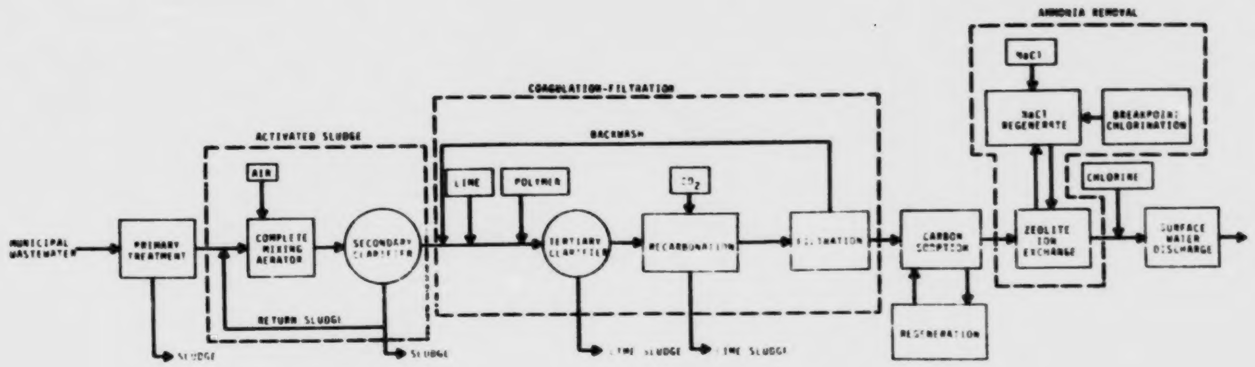
CHEMICAL SLUDGE OPTION / ORGANIC SLUDGE TREATMENT OPTIONS

UNIT OPERATION	12	1	2	3	4	5	6	7	8
THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	59x10^4 kwh 46x10^9 Btu	1.8x10^5 kwh 10x10^9 Btu	1.5x10^5 kwh 12x10^9 Btu	1.5x10^5 kwh 4.7x10^9 Btu	22,000 kwh	22,000 kwh	22,000 kwh	1.3x10^5 kwh	1.3x10^5 kwh
CONCRETE (CU YDS)	4350	3520	3600	3560	105,000	105,000	105,000	105,000	105,000
STEEL (TONS)	3700	2860	2780	3040	9600	9600	9600	10,000	10,000
CHEMICALS (LBS/DAY)		19,170-26,830	4500-5500	1170-5830	1170-5830	1170-5830	1170-5830	[illegible]	[illegible]
LAND (ACRES)	1200-1600	410-550	410-550	270-320	1370-1560	6000-27,000	26-36	820-1120	30-40
LABOR (MAN YRS/YR)	850-1150	384-492	267-354	310-360	200-600	132-178	131-178	250-290	250-280
OUTPUTS - BOD (MG/L)									
(LBS/DAY)									
SUSPENDED SOLIDS (MG/L)									
(LBS/DAY)									
NUTRIENTS. P (MG/L)									
(LBS/DAY)	16-23x10^6	5-7 x10^4	5-7 x10^4	5-7 x10^4	5-7x10^4	5-7x10^4	5-7x10^4	5-7x10^4	5-7x10^4
N (MG/L)									
(LBS/DAY)					.8-1x10^5	.8-1x10^5	.8-1x10^5	.8-1x10^5	.8-1x10^5
HEAVY METALS (LBS/DAY)	2500-50,000	.13-3.3x10^4	.13-3.3x10^4	.13-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4
ATMOSPHERIC EMISSIONS (LBS/DAY)		Metals=250-400 SO_2=440-670 HCl=80-120 NO_x=2500-3900 Particulates=4400-7000							
SLUDGES-% SOLIDS	100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	2.06x10^6	699,000	699,000	524,000	1.4x10^6	1.4x10^6	1.4x10^6	1.4x10^6	1.4x10^6
SOLID WASTE (CU FT/YR)		12-18x10^3	3000-3600	800-3800	800-3800	800-3800		9-12x10^3	9-12x10^3
NUISANCE - ODOR	None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE			Above Average						
TRAFFIC	50	17.5	17.5	13.1	35	35	.3	35	1
SAFETY (INJURIES/10^6 MAN-HRS)	41								
COSTS - CAPITAL ($ x 10^6)	73-99	34-47	50-68	110-150	44-52	7.1-9.7	16.1-21.8	36-48	35-47
RUNNING TOTAL CAPITAL ($ x 10^6)	436-469	470-516	486-537	546-619	480-521	443-479	452-491	472-517	471-516
LAND ($)	1.2-1.6x10^6	4.1-5.5x10^5	4.1-5.5x10^5	2.2-3.7x10^5	1.3-1.54 x10^5	6-28x10^6	26,000-36,000	.82-1.1x10^6	30,000-40,000
RUNNING GRAND TOTAL ($ x 10^6)	437-471	471-519	487-540	547-621	482-525	450-508	453-493	474-520	472-518
OPERATING (¢/1000 GAL)	5.3-8	4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	1.7-2.4	.22-.3	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	2.4-3.2	1.1-1.5	1.6-2.2	3.6-4.8	1.5-1.7	.4-1.2	.52-.7	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	7.7-12.2	5.5-8.4	4.6-6.9	7.2-9.9	4.6-5.8	2.1-3.6	.7-1.0	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	28.1-32.8	33.6-42.2	32.7-39.7	35.3-42.7	32.7-38.6	30.2-36.4	28.8-33.8	32.5-39.7	32-39.3

Activated Sludge-Coagulation-Filtration with Centrifugation-Recalcination of Chemical Sludge - 1000 MGD

PROCESS PROFILE SHEETS FOR TREATMENT STRATEGY # 9

Tertiary Treatment


MUNICIPAL WASTEWATER
PRIMARY TREATMENT
SLUDGE
ACTIVATED SLUDGE
AIR
COMPLETE MIXING AERATOR
SECONDARY CLARIFIER
RETURN SLUDGE
SLUDGE
COAGULATION-FILTRATION
BACKWASH
LIME
POLYMER
TERTIARY CLARIFIER
LIME SLUDGE
CO_2
RECARBONATION
LIME SLUDGE
FILTRATION
CARBON SORPTION
REGENERATION
AMMONIA REMOVAL
NaCl
NaCl REGENERATE
BREAKPOINT CHLORINATION
ZEOLITE ION EXCHANGE
CHLORINE
SURFACE WATER DISCHARGE

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 9 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Clarification Carbon Sorption Filtration	LIQUID DISPOSAL Surface Water	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	9 GRAVITY VACUUM FILTRATION INCINERATION LANDFILL	1 FLOTATION CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 FLOTATION PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 FLOTATION DIGESTION SAND DRYING LANDFILL	5 FLOTATION DIGESTION LAND SPREADING	6 DIGESTION OCEAN DUMPING	7 FLOTATION DIGESTION VACUUM FILTRATION LANDFILL	8 FLOTATION DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270 kwh	3734 kwh	90 Therms 21,600 kwh			3215 kwh 272x10⁶ Btu	1810 kwh 100x10⁶ Btu	1510 kwh 120x10⁶ Btu	1400 kwh 47x10⁶ Btu	220 kwh	220 kwh	Not Practical	1260 kwh	1260 kwh
CONCRETE (CU YDS)	756	2100	1400	252		68	30	28	34	1210	1210		1220	1220
STEEL (TONS)	75	290	390	16.7		70	55	56	70	120	120		120	125
CHEMICALS (LBS/DAY)	Polymer C-3385-21 Lime-21,000 Zeolite-884 HCl-1000 MgCO₃-840 CO₂-26,500 Cl₂-420						192-260	45-55	11-58	11-58	12-58		132-188	132-188
LAND (ACRES)		19	12			21-29	4.1-5.5	4.1-5.5	2.7-3.7	13.7-15.4	60-260		8.2-11.2	.34-.5
LABOR (MAN YRS/YR)	3.2	7.9	9.2			8.5-11.5	5.6-7.5	4.1-5.8	4.3-6.3	3.4-7.9	10.2-13.9		4.1-4.8	4.8-5.5
OUTPUTS - BOD (MG/L)	130	10-30	1											
(LBS/DAY)	10,400	830-2500	84											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	6600	830-2500	25											
NUTRIENTS: P (MG/L)	14.3	10	1											
(LBS/DAY)	1140	840	84			800-1150	500-700	500-700	500-700	500-700	500-700		500-700	500-700
N (MG/L)	32	25	.5-1											
(LBS/DAY)	2560	2100	42-84							800-1000	800-1000		800-1000	800-1000
HEAVY METALS (LBS/DAY)		25-500	Negligible			25-500	13-326	13-326	13-326	15-330	15-330		15-330	15-330
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=2.5-4 NO_x=25-39	SO_2=4.4-6.7 Particulates=44-70	HCl=.8-1.2					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	10,800	12,500	45,400			36,300	6990	6990	5240	14,000	14,000		14,000	14,000
SOLID WASTE (CU FT/YR)			17,800				120-180	30-36	7-38	7-38	8-38		90-120	90-120
NUISANCE - ODOR	Potential	Potential	Controlled			None	None	None	None	Potential	Potential		Potential	Potential
NOISE								Above Average						
TRAFFIC				.69		.91	.18	.18	.13	.35	.35		.35	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)						28.5								
COSTS - CAPITAL ($ x 10^6)	2.21	1.9-2	4.7	.043		1.5-1.9	1-1.3	1.2-1.3	1.8-2.1	.57-.64	.30-.40		.69-.85	1.1-1.3
RUNNING TOTAL CAPITAL ($ x 10^6)	2.21	4.11-4.21	8.8-8.9	8.9-9		10.4-10.9	11.4-12.2	11.6-12.2	12.2-13	11-11.5	10.7-11.3		11.1-11.8	11.5-12.2
LAND ($)		19,000	12,000			21-29x10^3	4100-5500	4100-5500	2700-3700	13,700-15,400	.6-2.6x10^5		8200-11,200	340-500
RUNNING GRAND TOTAL ($ x 10^6)	2.21	4.13-4.23	8.8-8.9	8.9-9		10.4-10.9	11.4-12.2	11.6-12.2	12.2-13	11-11.5	10.8-11.6		11.1-11.8	11.5-12.2
OPERATING (¢/1000 GAL)	4	3.4	18.4	.9		4.2-7.0	4.6-7.0	3.15-4.85	3.8-5.3	3.1-4.1	2.6-2.9		3.2-5.4	3.0-5.2
10% AMORTIZED (¢/1000 GAL)	7.1	6.1-6.4	15.1	.1		4.8-6.1	3.2-4.2	3.9-4.2	5.8-6.8	1.8-2.1	1.1-1.3		2.2-2.7	3.5-4.2
TOTAL OPERATING (¢/1000 GAL)	11.1	9.5-9.8	33.5	1.0		9.0-13.1	7.8-11.2	7.1-9.1	9.6-12.1	4.9-6.2	3.7-4.2		5.4-8.1	6.5-9.4
RUNNING TOTAL (¢/1000 GAL)	11.1	20.6-20.9	54.1-54.4	55.1-55.4		64.1-68.5	71.9-79.7	71.2-77.6	73.2-80.6	69-74.7	67.8-72.7		69.5-76.6	70.6-77.9

Tertiary Treatment with Filtration-
Incineration of Chemical Sludge - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 9 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Clarification Carbon Sorption- [illegible]	LIQUID DISPOSAL Surface Water	UNIT OPERATION	10	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION		FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270kwh	3734kwh	21,600kwh			6550 kwh 490×10^6 Btu	1810 kwh 100×10^6 Btu	1510 kwh 120×10^6 Btu	1460 kwh 47×10^6 Btu	220 kwh	220 kwh	Not Practical	1260 kwh	1260 kwh
CONCRETE (CU YDS)	756	2100	1400	252		95	30	28	34	1210	1210		1220	1220
STEEL (TONS)	75	290	390	16.7		98	55	56	70	120	120		120	125
CHEMICALS (LBS/DAY)	Polymer-2 [illegible]	Lime-6300 [illegible]	NaCl-1000 [illegible]	CO_2-26,300 Cl_2-420			192-260	45-55	11-58	11-58	12-58		132-188	132-188
LAND (ACRES)		19	12			13-17.5	4.1-5.5	4.1-5.5	2.7-3.7	13.7-15.4	60-260		8.2-11.2	.34-.5
LABOR (MAN YRS/YR)	3.2	7.9	9.2			14.4-18.6	5.6-7.5	4.1-5.8	4.3-6.3	3.4-7.9	10.2-13.9		4.2-4.8	4.8-5.5
OUTPUTS - BOD (MG/L)	130	10-30	1											
(LBS/DAY)	10,400	830-2500	84											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	6400	830-2500	25											
NUTRIENTS: P (MG/L)	16.3	10	1											
(LBS/DAY)	1160	840	86			1600-2300	500-700	500-700	500-700	500-700	500-700		500-700	500-700
N (MG/L)	32	25	.5-1											
(LBS/DAY)	2560	2100	42-84							900-1000	800-1000		800-1000	800-1000
HEAVY METALS (LBS/DAY)		25-500	Negligible			25-500	13-326	13-326	13-326	15-330	15-330		15-330	15-330
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=2.5-4 NO_x=25-39	SO_2=4.4-6.7 Particulates=44-70	HCl=.8-1.2					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	5-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	10,800	12,500	81,100			21,600	6990	6990	5240	14,000	14,000		14,000	14,000
SOLID WASTE (CU FT/YR)			8170				120-180	30-36	7-38	7-38	6-38		90-120	90-120
NUISANCE - ODOR	Potential	Potential	Controlled			None	None	None	None	Potential	Potential		Potential	Potential
NOISE								Above Average						
TRAFFIC				.32		.54	.18	.18	.13	.35	.35		.35	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)						28.5								
COSTS - CAPITAL ($ x 10^6)	2.21	1.9-2	4.7	.043		2.1-2.8	1-1.3	1.2-1.3	1.8-2.1	.57-.64	.3-.6		.69-.85	1.1-1.3
RUNNING TOTAL CAPITAL ($ x 10^6)	2.21	4.11-4.21	[illegible]	8.9-9		11-11.8	12-13.1	12.2-13.1	12.8-13.9	11.6-12.4	11.3-12.2		11.7-12.7	12.1-13.1
LAND ($)		19,000	12,000			$13\text{-}17.5\times10^3$	4100-5500	4100-5500	2700-3700	[illegible]	$.6\text{-}2.6\times10^5$		8200-11,200	340-500
RUNNING GRAND TOTAL ($ x 10^6)	2.21	[illegible]	[illegible]	8.9-9		11-11.8	12-13.1	12.2-13.1	12.8-13.9	11.6-12.4	11.4-12.5		11.7-12.7	11.1-13.1
OPERATING (¢/1000 GAL)	4	3.4	18.4	.9		4.8-11.4	4.6-7.0	3.15-4.85	3.8-5.3	3.1-4.1	2.6-2.9		3.2-5.4	3.0-5.2
10% AMORTIZED (¢/1000 GAL)	7.1	6.1-6.4	15.1	.1		6.8-9.1	3.2-4.2	3.9-4.2	5.8-6.8	1.8-2.1	1.1-1.3		2.2-2.7	3.5-4.2
TOTAL OPERATING (¢/1000 GAL)	11.1	9.5-9.8	33.5	1.0		11.6-20.5	7.8-11.2	7.1-9.1	9.6-12.1	4.9-6.2	3.7-4.2		5.4-8.1	6.5-9.4
RUNNING TOTAL (¢/1000 GAL)	11.1	20.6-20.9	54.1-54.4	55.1-55.4		66.7-75.9	74.5-87.1	73.8-85	76.3-88	71.6-82.1	70.4-80.1		72.1-84	73.2-85.3

Tertiary Treatment with Filtration-
Recalcination of Chemical Sludge - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 9 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Clarification Carbon Sorption Zeolite	LIQUID DISPOSAL Surface Water	UNIT OPERATION	11	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION		FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270kwh	3734kwh	[illegible]therms 21,600kwh			1740 kwh 272×10^6 Btu	1810 kwh 100×10^6 Btu	1510 kwh 120×10^6 Btu	1460 kwh 47×10^6 Btu	220 kwh	220 kwh	Not Practical	1260 kwh	1260 kwh
CONCRETE (CU YDS)	756	2100	1400	252		32	30	28	34	1210	1210		1220	1220
STEEL (TONS)	75	290	390	16.7		30	55	56	70	120	120		120	125
CHEMICALS (LBS/DAY)	Polymer-1 Lime-21,000 NaCl-1000 Cl_2-420 C-3185 Zeolite-84 Na_2CO_3-840 CO_2-24,500						192-268	45-55	11-58	11-58	12-58		132-188	132-188
LAND (ACRES)		19	12			21-29	4.1-5.5	4.1-5.5	2.7-3.7	13.7-15.4	60-260		8.2-11.2	.34-.5
LABOR (MAN YRS/YR)	3.2	7.9	9.2			7.2-9.8	5.6-7.5	4.1-5.8	4.3-6.3	3.4-7.9	10.2-13.9		4.1-4.8	4.8-5.5
OUTPUTS - BOD (MG/L)	130	10-30	1											
(LBS/DAY)	10,400	830-2500	84											
SUSPENDED SOLIDS (MG/L)	80	10-30	3											
(LBS/DAY)	6400	830-2500	25											
NUTRIENTS: P (MG/L)	14.3	10	1											
(LBS/DAY)	1140	840	84			800-1150	500-700	500-700	500-700	500-700	500-700		500-700	500-700
N (MG/L)	32	25	.5-1											
(LBS/DAY)	2560	2100	42-84							800-1000	800-1000		800-1000	800-1000
HEAVY METALS (LBS/DAY)		25-500	Negligible			25-500	13-326	13-326	13-326	15-330	15-330		15-330	15-330
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=2.5-4 NO_x=25-39	SO_2=4.4-6.7 Particulates=44-70	HCl=.8-1.2					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	10,800	12,500	45,400			36,300	6990	6990	5240	14,000	14,000		14,000	14,000
SOLID WASTE (CU FT/YR)			17,800				120-180	30-36	7-38	7-38	8-38		90-120	90-120
NUISANCE - ODOR	Potential	Potential	Controlled			None	None	None	None	Potential	Potential		Potential	Potential
NOISE								Above Average						
TRAFFIC				.69		.91	.18	.18	.13	.35	.35		.35	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)						28.5								
COSTS - CAPITAL ($\$ \times 10^6$)	2.21	1.9-2	4.7	.063		.53-1.2	1-1.3	1.2-1.3	1.8-2.1	.57-.64	.3-.4		.69-.85	1.1-1.3
RUNNING TOTAL CAPITAL ($\$ \times 10^6$)	2.21	4.11-4.21	8.8-8.9	8.9-9		9.7-10.2	10.7-11.5	10.9-11.5	11.5-12.3	10.3-10.8	10-10.6		10.4-11.1	10.8-11.5
LAND ($)		19,000	12,000			21-29 x 10^3	4100-5500	4100-5500	2700-3700	13,700-15,400	.6-2.6x10^5		8200-11,200	340-500
RUNNING GRAND TOTAL ($\$ \times 10^6$)	221	4.13-4.23	8.8-8.9	8.9-9		9.7-10.2	10.7-11.5	10.9-11.5	11.5-12.3	10.3-10.8	10.1-10.9		10.4-11.1	10.8-11.5
OPERATING (¢/1000 GAL)	4	3.4	18.4	.9		3.7-4.9	4.6-7.0	3.15-4.85	3.8-5.3	3.1-4.1	2.6-2.9		3.2-5.4	3.0-5.2
10% AMORTIZED (¢/1000 GAL)	7.1	6.1-6.4	15.1	.1		2.7-3.9	3.2-4.2	3.9-4.2	5.8-6.8	1.8-2.1	1.1-1.3		2.2-2.7	3.5-4.2
TOTAL OPERATING (¢/1000 GAL)	11.1	9.5	33.5	1.0		6.4-8.8	7.8-11.2	7.1-9.1	9.6-12.1	4.9-6.2	3.7-4.2		5.4-8.1	6.5-9.4
RUNNING TOTAL (¢/1000 GAL)	11.1	20.6-20.9	54.1-54.4	55.1-55.4		61.5-64.2	69.3-75.4	68.6-73.3	71.1-76.3	66.4-70.4	65.2-68.4		66.9-72.3	68-73.6

Tertiary Treatment with Centrifugation-Incineration of Chemical Sludge - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 9 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Clarification Carbon Sorption-	LIQUID DISPOSAL Surface Water	UNIT OPERATION	12	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION		FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270kwh	3734kwh	21,600kwh			6190 kwh 490x10⁶ Btu	1010 kwh 100x10⁶ Btu	1510 kwh 120x10⁶ Btu	1460 kwh 47x10⁶ Btu	220 kwh	220 kwh	Not Practical	1260 kwh	1260 kwh
CONCRETE (CU YDS)	756	2100	1400	252		45	30	28	36	1210	1210		1220	1220
STEEL (TONS)	75	290	390	16.7		53	55	56	70	120	120		120	125
CHEMICALS (LBS/DAY)	Polymer 21 C-33[illegible]	Lime [illegible] Zeolite [illegible]	[illegible]	1000 Cl2-420 CO2-[illegible],500			192-268	45-55	11-58	11-58	12-58		132-188	132-188
LAND (ACRES)		19	12			13-17	4.1-5.5	4.1-5.5	2.7-3.7	13.7-15.4	60-260		8.2-11.2	.36-.5
LABOR (MAN YRS/YR)	3.2	7.9	9.2			10-16	5.6-7.5	4.1-5.8	4.3-6.3	3.4-7.9	10.2-13.9		6.1-6.8	4.8-5.5
OUTPUTS - BOD (MG/L)	130	10-30	1											
(LBS/DAY)	10,400	830-2500	84											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	6400	830-2500	25											
NUTRIENTS: P (MG/L)	14.3	10	1											
(LBS/DAY)	1140	840	84			1600-2300	500-700	500-700	500-700	500-700	500-700		500-700	500-700
N (MG/L)	32	25	.5-1											
(LBS/DAY)	2560	2100	42-84							800-1000	800-1000		800-1000	800-1000
HEAVY METALS (LBS/DAY)		25-500	Negligible			25-500	13-326	13-326	13-326	15-330	15-330		15-330	15-330
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=2.5-4 NO$_x$=25-39	SO$_2$=4.4-6.7 Particulates=44-70	HCl=.8-1.2					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	10,800	12,500	81,100			21,600	6990	6990	5240	14,000	14,000		14,000	14,000
SOLID WASTE (CU FT/YR)			8170				120-180	30-36	7-38	7-38	8-38		90-120	90-120
NUISANCE - ODOR	Potential	Potential	Controlled			None	None	None	None	Potential	Potential		Potential	Potential
NOISE								Above Average						
TRAFFIC				.32		.54	.18	.18	.13	.35	.35		.35	Negligible
SAFETY (INJURIES/10⁶ MAN-HRS)						28.5								
COSTS - CAPITAL ($ x 10⁶)	2.21	1.9-2	4.7	.043		1.7-2.3	1-1.3	1.2-1.3	1.8-2.1	.57-.64	.3-.4		.69-.85	1.1-1.3
RUNNING TOTAL CAPITAL ($ x 10⁶)	2.21	4.11-4.21	8.8-8.9	8.9-9		10.6-11.3	11.6-12.6	11.8-12.6	12.4-13.4	11.2-11.9	10.9-11.7		11.3-12.2	11.7-12.6
LAND ($)		19,000	12,000			13-17x10³	4100-5500	4100-5500	2700-3700	13,700-15,400	.6-2.6x10⁵		8200-11,200	340-500
RUNNING GRAND TOTAL ($ x 10⁶)	2.21	4.13-4.23	8.8-8.9	8.9-9		10.6-11.3	11.6-12.6	11.8-12.6	12.4-13.4	11.2-11.9	11-12		11.3-12.2	11.7-12.6
OPERATING (¢/1000 GAL)	4	3.6	18.4	.9		5.3-9.1	4.6-7.0	3.15-4.85	3.8-5.3	3.1-4.1	2.6-2.9		3.2-5.6	3.0-5.2
10% AMORTIZED (¢/1000 GAL)	7.1	6.1-6.4	15.1	.1		5.5-7.6	3.2-4.2	3.9-4.2	5.8-6.8	1.8-2.1	1.1-1.3		2.2-2.7	3.5-4.2
TOTAL OPERATING (¢/1000 GAL)	11.1	9.5-9.8	33.5	1.0		10.8-16.7	7.8-11.2	7.1-9.1	9.6-12.1	4.9-6.2	3.7-4.2		5.4-8.1	6.5-9.4
RUNNING TOTAL (¢/1000 GAL)	11.1	20.6-20.9	54.1-54.4	55.1-55.4		65.9-72.1	73.7-83.3	73-81.2	75.5-84.2	70.8-78.3	69.6-76.3		71.3-80.2	72.4-81.5

Tertiary Treatment with Centrifugation-
Recalcination of Chemical Sludge - 10 MGD

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PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 9 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT				CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Clarification Carbon Sorption Zeolite	LIQUID DISPOSAL Surface Water	9	1	2	3	4	5	6	7	8
UNIT OPERATION THICKENING:					GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
CONDITIONING:						CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
DEWATERING:					VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
DISPOSAL:					INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	4000 kwh	11,900 kwh	900 Therms $1.48\times10^{?}$ kwh		3.2×10^4 kwh 2.7×10^9 Btu	18,100 kwh 1×10^9 Btu	15,100 kwh 1.2×10^9 Btu	14,600 kwh 470×10^6 Btu	2200 kwh	2200 kwh	2200 kwh	12,600 kwh	12,600 kwh
CONCRETE (CU YDS)	6240	14,000	16,000	2120	370	365	342	373	10,500	10,500	10,500	10,500	10,500
STEEL (TONS)	545	1600	1880	140	400	300	295	340	960	960	960	1000	1000
CHEMICALS (LBS/DAY)	Polymer-210 Lime 2.1×10^5 NaCl-10,000 Cl_2-4200, F-31,850 Zeolite-8840 Na_2CO_3-8400 CO_2-2.65×10^5					1917-2683	450-550	117-583	117-583	117-583	117-583	1317-1880	1317-1880
LAND (ACRES)		38	27		210-290	41-55	41-55	27-37	137-154	603-2603	2.6-3.6	82-112	3-4
LABOR (MAN YRS/YR)	28	41	57		61-83	38.4-49.2	26.7-35.4	31-36	20-60	13.6-18.4	13.6-18.4	25-29	25-28
OUTPUTS - BOD (MG/L)	130	10-30	1										
(LBS/DAY)	1.04×10^5	$8-3\times10^4$	840										
SUSPENDED SOLIDS (MG/L)	80	10-30	.1										
(LBS/DAY)	64,000	$8-3\times10^4$	250										
NUTRIENTS: P (MG/L)	14.3	10	1										
(LBS/DAY)	11,400	8400	840		8000-11,500	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000
N (MG/L)	32	25	.5-1										
(LBS/DAY)	25,600	21,000	420-840						8000-10,000	8000-10,000	8000-10,000	8000-10,000	8000-10,000
HEAVY METALS (LBS/DAY)		250-5000	Negligible		250-5000	125-3260	125-3260	125-3260	150-3300	150-3300	150-3300	150-3300	150-3300
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=25-40 NO_x=250-390	SO_2=44-67 Particulates=440-700	HCl=8-12					
SLUDGES-% SOLIDS	5	1	1-5		100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	108,000	125,000	454,000		361,000	69,900	69,900	52,400	140,000	140,000	140,000	140,000	140,000
SOLID WASTE			1.78×10^5			1200-1800	300-360	80-180	80-180	80-180		900-1200	900-1200
NUISANCE - ODOR	Potential	Potential	Controlled		None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE							Above Average						
TRAFFIC				6.9	9.1	1.75	1.75	[illegible]	2.2	2.2	.03	3.5	.1
SAFETY (INJURIES/10^6 MAN-HRS)					41								
COSTS - CAPITAL ($ x 10^6)	11.7	14-15	23.8	.13	5.2-6.9	3.4-4.7	5-6.8	11-15	4.4-5.2	5.1-6.9	14.7-19.9	3.7-4.9	3.5-4.2
RUNNING TOTAL CAPITAL ($ x 10^6)	11.7	25.7-26.7	49.5-50.5	49.7-50.7	54.9-57.6	58.3-62.3	59.9-64.4	65.9-72.6	59.3-62.6	60-64.5	69.6-77.5	58.6-62.5	58.4-62.3
LAND ($)		38,000	27,000		$2.1-2.9\times10^5$	41,000-55,000	41,000-55,000	27,000-37,000	[illegible]-1.54	$.6-2.6\times10^6$	2600-3600	$.82-1.1\times10^5$	3000-4000
RUNNING GRAND TOTAL ($ x 10^6)	11.7	25.7-26.7	49.6-50.6	49.7-50.7	55.1-57.9	58.5-62.7	60.1-64.9	66.1-72.9	59.6-63.3	60.8-67.4	69.8-77.8	58.9-62.9	58.6-62.6
OPERATING (¢/1000 GAL)	2.6	1.2	12.6	.7	4-6.8	4.4-6.9	2.95-4.65	3.6-5.1	[illegible]	2.2-2.8	.54-.73	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.8	4.3-4.8	7.7	.04	1.7-2.3	1.1-1.5	1.6-2.2	3.6-4.8	[illegible]	1.8-3.1	4.7-6.4	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	6.4	5.7-6	20.3	.7	5.7-9.1	5.5-8.4	4.6-6.9	7.2-9.9	4.5-5.8	4.0-5.9	5.2-7.1	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	6.4	12.1-12.4	32.4-32.7	33.1-33.4	38.4-42.5	44.3-50.9	43.6-49.[illegible]	46-52.[illegible]	43.3-48.3	42.8-48.4	44.0-49.6	42.2-49.4	42.7-49.[illegible]

Tertiary Treatment with Filtration-
Incineration of Chemical Sludge - 100 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 9 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Clarification Carbon Sorption Zeolite	LIQUID DISPOSAL Surface Water	UNIT OPERATION	10	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	4000 kwh	11,900 kwh	900 Therms 1.68x10[illegible] kwh			8.5x10[illegible] kwh 4.9x10[illegible] Btu	18,100 kwh 1×10^9 Btu	15,100 kwh 1.2×10^9 Btu	14,600 kwh 470×10^6 Btu	2200 kwh	2200 kwh	2200 kwh	12,600 kwh	12,600 kwh
CONCRETE (CU YDS)	6240	14,000	16,000	2120		518	365	342	373	10,500	10,500	10,500	10,500	10,500
STEEL (TONS)	545	1600	1880	140		560	300	295	340	960	960	960	1000	1000
CHEMICALS (LBS/DAY)	Polymer-210 Lime-63,000 NaCl 10,000 Cl_2-4200 C-33850 Zeolite-8840 Na_2CO_3-8400 CO_2-2.63×10^5						1917-2683	450-550	117-583	117-583	117-583	117-583	1317-1880	1317-1880
LAND (ACRES)		38	27			130-175	41-55	41-55	27-37	137-154	603-2603	2.6-3.6	82-112	3-4
LABOR (MAN YRS/YR)	28	41	57			95-129	38.4-49.2	26.7-35.4	31-36	20-60	13.6-18.4	13.6-18.4	25-29	25-28
OUTPUTS - BOD (MG/L)	130	10-30	1											
(LBS/DAY)	1.04×10^5	$.8-3\times10^4$	840											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	64,000	$.8-3\times10^4$	250											
NUTRIENTS: P (MG/L)	14.3	10	1											
(LBS/DAY)	11,400	8400	840			$16-23\times10^3$	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000
N (MG/L)	32	25	.5-1											
(LBS/DAY)	25,600	21,000	420-8840							8000-10,000	8000-10,000	8000-10,000	8000-10,000	8000-10,000
HEAVY METALS (LBS/DAY)		250-5000	Negligible			250-5000	125-3260	125-3260	125-3260	150-3300	150-3300	150-3300	150-3300	150-3300
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals-25-40 NO_x-250-390	SO_2-44-67 Particulates-440-700	HCl-8-12					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	108,000	125,000	811,000			216,000	69,900	69,900	52,400	140,000	140,000	140,000	140,000	140,000
SOLID WASTE (CU FT/YR)			8.2×10^4				1200-1800	300-360	80-380	80-380	80-380		900-1200	900-1200
NUISANCE - ODOR	Potential	Potential	Controlled			None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE								Above Average						
TRAFFIC				32		5.4	1.75	1.75	1.3	1.3	3.5	.1	3.5	.03
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($ x 10^6)	11.7	14-15	28.3	.13		10.1-13.9	3.4-4.7	5-6.8	11-15	4.5-5.4	5.1-6.9	14.7-19.9	3.7-4.9	3.5-4.7
RUNNING TOTAL CAPITAL ($ x 10^6)	11.7	25.7-26.7	49.5-50.5	49.7-50.7		60-64.6	63.4-69.3	65-71.4	71-79.6	64.5-70	65.1-71.5	74.7-84.5	63.7-69.5	63.5-69.3
LAND ($)		38,000	27,000			$1.3-1.75\times10^5$	41,000-55,000	41,000-55,000	27,000-37,000	$1.37-1.54\times10^5$	$.6-2.6\times10^6$	2600-3600	$.82-1.1\times10^5$	3000-4000
RUNNING GRAND TOTAL ($ x 10^6)	11.7	25.7-26.7	49.6-50.6	49.7-50.7		60.1-64.6	63.5-69.6	65.1-71.7	71.1-79.6	64.7-72.6	65.8-74.3	74.8-84.7	63.9-69.8	63.6-69.5
OPERATING (¢/1000 GAL)	2.6	1.2	12.6	.7		5.1-11.7	4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	2.2-2.8	.54-.73	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.8	4.5-4.8	7.7	.04		3.4-4.5	1.1-1.5	1.6-2.2	3.6-4.8	1.4-1.7	1.8-3.1	4.7-6.4	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	6.4	5.7-6	20.3	.7		8.5-16.2	5.5-8.4	4.6-6.9	7.2-9.9	4.5-5.8	4.0-5.9	5.2-7.1	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	6.4	12.1-12.4	32.4-32.7	33.1-33.4		41.6-49.6	47.1-58	46.2-56.3	48.8-55.5	46.1-55.4	45.6-55.5	46.8-56.7	46-56.5	45.5-56.1

Tertiary Treatment with Filtration-
Recalcination of Chemical Sludge - 100 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 9 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Clarification Carbon Sorption Zeolite	LIQUID DISPOSAL Surface Water	UNIT OPERATION	11	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	CATIONIC	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	4000 kwh	11,900 kwh	900 Therms 1.68x10^{9} kwh			1.7x10^{4} kwh 2.7x10^{9} Btu	18,100 kwh 1x10^{9} Btu	15,100 kwh 1.5x10^{9} Btu	14,600 kwh 470x10^{6} Btu	2200 kwh	2200 kwh	2200 kwh	12,600 kwh	12,600 kwh
CONCRETE (CU YDS)	6240	16,000	16,000	2120		320	365	342	373	10,500	10,500	10,500	10,500	10,500
STEEL (TONS)	545	1600	1880	340		270	300	295	340	960	960	960	1000	1000
CHEMICALS (LBS/DAY)	Polymer- C-31850	210 Lime Zeolite	2.1x10^{5} 8840	NaCl-10,000 Cl$_2$-4200 Na$_2$CO$_3$-8400 CO$_2$-2.65x10^{5}			1917-2683	450-550	117-583	117-583	117-583	117-583	1317-1880	1317-1880
LAND (ACRES)		38	27			210-280	41-55	41-55	27-37	137-154	603-2603	2.6-3.6	82-112	3-4
LABOR (MAN YRS/YR)	28	41	57			54-72	38.4-49.2	26.7-35.4	31-36	20-60	13.6-18.4	13.6-18.4	25-29	25-28
OUTPUTS - BOD (MG/L)	130	10-30	1											
(LBS/DAY)	1.04x10^{5}	.8-3x10^{4}	840											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	64,000	.8-3x10^{4}	250											
NUTRIENTS: P (MG/L)	14.3	10	1											
(LBS/DAY)	11,400	8400	840			8000-11,500	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000
N (MG/L)	32	25	.5-1											
(LBS/DAY)	25,600	21,000	420-840							8000-10,000	8000-10,000	8000-10,000	8000-10,000	8000-10,000
HEAVY METALS (LBS/DAY)		250-5000	Negligible			250-5000	125-3260	125-3260	125-3260	150-3300	150-3300	150-3300	150-3300	150-3300
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=25-40 NO$_x$=250-390	SO$_2$=44-67 Particulates=440-700	HCl=8-12					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	108,000	125,000	454,000			363,000	69,900	69,900	52,400	140,000	140,000	140,000	140,000	140,000
SOLID WASTE (CU FT/YR)			1.78x10^{5}				1200-1800	300-360	80-380	80-380	80-380		900-1200	900-1200
NUISANCE - ODOR	Potential	Potential	Controlled			None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE								Above Average						
TRAFFIC				6.9		9.1	1.75	1.75	1.3	3.5	3.5	.03	3.5	.1
SAFETY (INJURIES/10^{6} MAN-HRS)						41								
COSTS - CAPITAL ($ x 10^{6})	11.7	14-15	23.8	.13		3.2-4.3	3.4-4.7	5-6.8	11-15	4.5-5.4	5.1-6.9	14.7-19.9	3.7-4.9	3.5-4.7
RUNNING TOTAL CAPITAL ($ x 10^{6})	11.7	25.7-26.7	49.5-50.5	49.7-50.7		52.9-55	56.3-59.7	57.9-61.8	63.9-70	57.4-60.4	58-61.9	67.6-74.9	56.6-59.9	56.4-59.7
LAND ($)		38,000	27,000			2.1-2.9x10^{5}	41,000-55,000	41,000-55,000	27,000-37,000	1.37-1.54 x10^{5}	.6-2.6x10^{6}	2600-3600	.82-1.1x10^{5}	3000-4000
RUNNING GRAND TOTAL ($ x 10^{6})	11.7	25.7-26.7	49.6-50.6	49.7-50.7		53.1-55.3	56.5-60.1	58.1-62.2	64.1-70.3	57.7-60.9	58.8-64.8	67.8-75.2	56.9-60.3	56.6-60
OPERATING (¢/1000 GAL)	2.6	1.2	12.6	.7		3.4-4.6	4.4-6.9	2.95-4.65	3.6-5.1	3.8-5.7	2.2-2.8	.54-.73	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.8	4.5-4.8	7.7	.04		1.1-1.5	1.1-1.5	1.6-2.2	3.6-4.8	1.4-1.7	1.8-3.1	4.7-6.4	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	6.4	5.7-6	20.3	.7		4.5-6.1	5.5-8.4	4.6-6.9	7.2-9.9	4.5-5.8	4.0-5.9	5.2-7.1	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	6.4	12.1-12.4	32.4-32.7	33.1-33.4		37.6-39.5	43.1-47.9	42.2-46.4	44.8-49.4	42.1-45.3	41.6-45.4	42.8-46.6	42-46.4	41.5-46

Tertiary Treatment with Centrifugation-
Incineration of Chemical Sludge - 100 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 9 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Clarification Carbon Sorption Zeolite	LIQUID DISPOSAL Surface Water	UNIT OPERATION	12	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	4000 kwh	11,900 kwh	900 Therms 1.48x10 kwh			6.2x10 kwh 4.9x10^9 Btu	18,100 kwh 1x10^9 Btu	15,100 kwh 1.2x10^9 Btu	14,600 kwh 670x10^6 Btu	2200 kwh	2200 kwh	2200 kwh	12,600 kwh	12,600 kwh
CONCRETE (CU YDS)	6240	14,000	16,000	2120		44.8	365	342	373	10,500	10,500	10,500	10,500	10,500
STEEL (TONS)	545	1600	1880	140		378	300	295	340	960	960	960	1000	1000
CHEMICALS (LBS/DAY)	Polymer-210 Lime-63,000 NaCl-10,000 Cl_2-4200, C-33850 Zeolite-8840 Na_2CO_3-8400 CO_2-2.65x10^5						1917-2683	450-550	117-583	117-583	117-583	117-583	1317-1880	1317-1880
LAND (ACRES)		38	27			130-170	41-55	41-55	27-37	137-154	603-2603	2.6-3.6	82-112	3-4
LABOR (MAN YRS/YR)	28	41	57			88-120	38.4-49.2	26.7-35.4	31-36	20-60	13.6-18.4	13.6-18.4	25-29	25-28
OUTPUTS - BOD (MG/L)	130	10-30	1											
(LBS/DAY)	1.04x10^5	.8-3x10^4	840											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	64,000	.8-3x10^4	250											
NUTRIENTS: P (MG/L)	14.3	10	1											
(LBS/DAY)	11,400	8400	840			16-23x10^3	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000	5000-7000
N (MG/L)	32	25	.5-1											
(LBS/DAY)	25,600	21,000	420-840							8000-10,000	8000-10,000	8000-10,000	8000-10,000	8000-10,000
HEAVY METALS (LBS/DAY)		250-5000	Negligible			250-5000	125-3260	125-3260	125-3260	150-3300	150-3300	150-3300	150-3300	150-3300
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=25-40 NO_x=250-390	SO_2=44-67 Particulates=440-700	HCl=8-12					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	108,000	125,000	811,000			216,000	69,900	69,900	52,400	140,000	140,000	140,000	140,000	140,000
SOLID WASTE (CU FT/YR)			8.2x10^4				1200-1800	300-360	80-380	80-380	80-380		900-1200	900-1200
NUISANCE - ODOR	Potential	Potential	Controlled			None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE								Above Average						
TRAFFIC				32		5.4	1.72	1.75	1.3	3.5	3.5	.03	3.5	.1
SAFETY (INJURIES/10^6 MAN-HRS)						<1								
COSTS - CAPITAL ($ x 10^6)	11.7	14-15	23.8	.13		7.4-10.1	4.4-4.7	5-6.8	11-15	4.4-5.2	5.1-6.9	14.7-19.9	3.7-4.9	3.5-4.7
RUNNING TOTAL CAPITAL ($ x 10^6)	11.7	25.7-26.7	49.5-50.5	49.7-50.7		57.1-60.8	60.5-65.5	62.1-67.6	68.1-75.8	61.5-66	62.2-67.7	71.8-80.7	60.8-65.7	60.6-65.5
LAND ($)		14,000	27,000			1.3-1.7x10^5	41,000-55,000	41,000-55,000	27,000-37,000	1.3-1.54 x10^5	.6-2.6x10^6	2600-3600	.82-1.1x10^5	3000-4000
RUNNING GRAND TOTAL ($ x 10^6)	11.7	25.7-26.7	49.6-50.6	49.7-50.7		57.2-61	60.6-65.8	62.2-67.9	68.2-76	61.7-66.4	62.9-70.5	71.9-80.9	61-66	60.7-65.7
OPERATING (¢/1000 GAL)	2.6	1.2	12.6	.7		5.6-9.4	4.4-6.9	2.95-4.65	3.6-5.1	3.8-5.7	2.2-2.8	.54-.73	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.8	4.5-4.8	7.7	.04		2.4-3.3	1.1-1.5	1.6-2.2	3.6-4.8	1.4-1.7	1.8-3.1	4.7-6.4	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	6.4	5.7-6	20.3	.7		8-12.7	5.5-8.4	4.6-6.9	7.2-9.9	4.5-5.8	4.0-5.9	5.2-7.1	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	6.4	12.1-12.4	32.4-32.2	33.1-33.4		41.1-46.1	46.6-54.5	45.7-53	48.3-56	45.6-51.9	45.2-52	46.3-53.2	45.5-53	45-52.6

Tertiary Treatment with Centrifugation-
Recalcination of Chemical Sludge - 100 MGD

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PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 9 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Clarification Carbon Sorption Zeolite	LIQUID DISPOSAL Surface Water	UNIT OPERATION	9	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNIT./DAY)	40,000 kwh	1.19x 10^5 kwh	9000 Therms 1.48x10^5 kwh			32x10^6 kwh 27x10^9 Btu	1.8x10^5 kwh 10x10^9 Btu	1.5x10^5 kwh 12x10^9 Btu	1.5x10^5 kwh 6.2x10^9 Btu	22,000 kwh	22,000 kwh	22,000 kwh	1.3x10^5 kwh	1.3x10^5 kwh
CONCRETE (CU YDS)	61,600	166,000	160,000	19,300		3600	3520	3400	3560	105,000	105,000	105,000	105,000	105,000
STEEL (TONS)	5400	17,400	18,500	1270		3900	2860	2780	3060	9600	9600	9600	10,000	10,000
CHEMICALS (LBS/DAY)	Polymer-2100 Lime-2.1x10^6 Na2CO3-84,000 Cl2-42,000 C-338,500 NaCl-1x10^5 CO2-2.65x10^6 Zeolite 88,400						19,170-26,830	4500-5500	1170-5830	1170-5830	1170-5830	1170-5830	[illegible]	[illegible]
LAND (ACRES)		190	80			2100-2900	410-550	410-550	270-370	1370-1560	8000-27,000	26-36	820-1120	30-40
LABOR (MAN YRS/YR)	280	410	570			610-830	384-492	267-354	310-360	200-600	132-178	131-178	250-290	250-280
OUTPUTS - BOD (MG/L)	130	10-30	1											
(LBS/DAY)	1.04x10^6	8-3x10^5	8400											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	6.4x10^5	.8-3x10^5	2500											
NUTRIENTS: P (MG/L)	14.3	10	1											
(LBS/DAY)	114,000	84,000	8400			8-11.5x10^4	5-7 x10^4	5-7 x10^4	5-7 x10^4	5-7x10^4	5-7x10^4	5-7x10^4	5-7x10^4	5-7x10^4
N (MG/L)	32	25	.5-1											
(LBS/DAY)	2.56x10^5	2.1x10^5	4200-8400							.8-1x10^5	.8-1x10^5	.8-1x10^5	.8-1x10^5	.8-1x105
HEAVY METALS (LBS/DAY)		2500-50,000		2500-50,000		2500-50,000	.13-3.3x10^4	.13-3.3x10^4	.13-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=250-400 SO2=440-670 HCl=80-120 NOx=2500-3900 Particulates=4400-7000							
SLUDGES % SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT (LBS/DAY)	1.08x10^6	1.25x10^6	4.54x10^6			1.63x10^6	693,000	699,000	224,000	1.4x10^6	1.4x10^6	1.4x10^6	1.4x10^6	1.4x10^6
SOLID WASTE (CU FT/YR)			1.78x10^6				12-18x10^3	3000-3600	800-3800	800-3800	800-3800		9-12x10^3	9-12x10^3
NUISANCE - ODOR	Potential	Potential	Controlled			None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE								Above Average						
TRAFFIC				69		91	17.5	17.5	13.1	35	35	.3	35	1
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($ x 10^6)	117	143-150	238	1.3		52-69	34-47	50-68	110-150	44-52	7.1-9.7	16.1-21.8	36-48	35-47
RUNNING TOTAL CAPITAL ($ x 10^6)	117	260-267	498-505	499-506		551-575	585-622	601-643	661-725	595-627	558-585	567-597	587-623	586-622
LAND ($)		190,000	80,000			2.1-2.9x10^6	4.1-5.5x10^5	4.1-5.5x10^5	2.7-3.7x10^5	1.32-1.54x10^6	6-27x10^6	26,000-36,000	.82-1.1x10^6	30,000-40,000
RUNNING GRAND TOTAL ($ x 10^6)	117	260-267	498-505	499-506		553-578	587-626	603-647	663-728	598-632	566-615	569-600	590-627	588-625
OPERATING (¢/1000 GAL)	2.0	1.0	12.6	.5		4-6.8	4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	1.7-2.4	.22-.3	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.7	4.6-4.8	7.7	.04		1.7-2.3	1.1-1.5	1.6-2.2	3.6-4.8	1.5-1.7	.4-1.2	.52-.7	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	5.7	5.6-5.8	20.3	.5		5.7-9.1	5.5-8.4	4.6-6.9	7.2-9.9	4.6-5.8	2.1-3.6	.7-1.0	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	5.7	11.3-11.5	31.6-31.8	32.1-32.7		37.8-41.6	43.3-49.8	42.4-48.3	45-51.3	42.4-47.2	36.9-49.2	38.5-42.4	42.2-48.3	41.7-47.9

Tertiary Treatment with Filtration-
Incineration of Chemical Sludge - 1000 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 9 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Clarification Carbon Sorption Zeolite	LIQUID DISPOSAL Surface Water	UNIT OPERATION	10	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	40,000 kwh	1.19x 10^5 kwh	9200 Therms 1.48x10 kwh			85x10^4 kwh 49x10^9 Btu	1.8x10^5 kwh 10x10^9 Btu	1.5x10^5 kwh 12x10^9 Btu	1.5x10^5 kwh [illegible]x10^9 Btu	22,000 kwh	22,000 kwh	22,000 kwh	1.3x10^5 kwh	1.3x10^5 kwh
CONCRETE (CU YDS)	61,600	166,000	160,000	19,300		5000	3520	3400	3[illegible]60	105,000	105,000	105,000	105,000	105,000
STEEL (TONS)	5400	17,400	18,500	1270		5600	2860	2780	[illegible]040	9600	9600	9600	10,000	10,000
CHEMICALS (LBS/DAY)	Polymer-2100 Lime 6.3x10^5 NaCl-100,000 Cl_2-42,00 C-338,500 Zeolite-88,400 Na_2[illegible]-84,000 CO_2-2.65						19,170-26,830	4500-5500	1170-5830	1170-5830	1170-5830	1170-5830	13,170-[illegible]	13,170-[illegible]
LAND (ACRES)		190	80			1300-1750	410-550	410-550	270-370	1370-1540	6000-27,000	26-36	820-1120	30-40
LABOR (MAN YRS/YR)	280	410	570			[illegible]-1290	384-492	267-354	310-360	200-600	132-178	131-178	250-290	250-280
OUTPUTS - BOD (MG/L)	130	10-30	1											
(LBS/DAY)	1.04x10^6	.8-3x10^5	8400											
SUSPENDED SOLIDS (MG/L)	80	10-30	13											
(LBS/DAY)	6.4x10^5	.8-3x10^5	2500											
NUTRIENTS: P (MG/L)	14.3	10	1											
(LBS/DAY)	114,000	84,000	8400			16-23x10^4	5-7 x10^4	5-7 x10^4	5-7 x10^4	5-7x10^4	5-7x10^4	5-7x10^4	5-7x10^4	5-7x10^4
N (MG/L)	32	25	.5-1											
(LBS/DAY)	2.56x10^5	2.1x10^5	4200-8400							.8-1x10^5	.8-1x10^5	.8-1x10^5	.8-1x10^5	.8-1x10^5
HEAVY METALS (LBS/DAY)		2500-50,000		2500-50,000		2500-50,000	.13-3.3x10^4	.13-3.3x10^4	.13-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4	.15-3.3x10^4
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=250-400 SO_2=440-670 HCl=83-120 NO_x=2500-3900 Particulates=4400-7000							
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	1.08x10^6	1.25x10^6	8.11x10^5			2.16x10^6	699,000	699,000	524,000	1.4x10^6	1.4x10^6	1.4x10^6	1.4x10^6	1.4x10^6
SOLID WASTE (CU FT/YR)			8.2x10^5				12-18x10^3	1000-1600	800-3800	800-3800	800-3800		9-12x10^3	9-12x10^3
NUISANCE - ODOR	Potential	Potential	Controlled			None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE								Above Average						
TRAFFIC				69		5	17.5	17.5	13.1	35	35	.3	35	1
SAFETY (INJURIES/10^6 MAN-HRS)						42								
COSTS - CAPITAL ($ x 10^6)	117	143-150	238	1.3		103-139	34-47	50-68	110-150	44-52	7.1-9.7	16.1-21.8	36-48	35-47
RUNNING TOTAL CAPITAL ($ x 10^6)	117	260-267	498-505	499-506		602-645	636-692	652-713	712-795	646-697	609-655	618-667	638-693	637-692
LAND ($)		190,000	80,000			1.3-1.75x10^6	4.1-5.5x10^5	4.1-5.5x10^5	2.7-3.7x10^5	1.37-1.54 x10^6	6-27x10^6	26,000-36,000	.82-1.1x10^6	30,000-40,000
RUNNING GRAND TOTAL ($ x 10^6)	117	260-267	498-505	499-506		603-647	637-695	653-716	713-797	648-701	616-684	619-669	640-696	638-694
OPERATING (¢/1000 GAL)	2.0	1.0	12.6	.5		5.1-11.7	4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	1.7-2.4	.22-.3	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.7	4.6-4.8	7.7	.04		3.4-4.5	1.1-1.5	1.6-2.2	3.6-4.8	1.5-1.7	.4-1.2	.52-.7	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	5.7	5.6-5.8	203	.5		8.5-16.2	5.5-8.4	4.6-6.9	7.2-9.9	4.6-5.8	2.1-3.6	.7-1.0	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	5.7	11.3-11.5	31.6-31.8	32.1-32.3		40.6-48.5	46.1-56.9	45.2-55.4	47.8-58.4	45.2-54.3	44.9-56.3	41.3-49.5	45.0-55.4	44.5-55

Tertiary Treatment with Filtration-
Recalcination of Chemical Sludge - 1000 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 9 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Clarification Carbon Sorption Zeolite	LIQUID DISPOSAL Surface Water	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	11 GRAVITY CENTRIFUGE INCINERATION LANDFILL	1 FLOTATION CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 FLOTATION PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 FLOTATION DIGESTION SAND DRYING LANDFILL	5 FLOTATION DIGESTION LAND SPREADING	6 FLOTATION DIGESTION OCEAN DUMPING	7 FLOTATION DIGESTION VACUUM FILTRATION LANDFILL	8 FLOTATION DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	40,000 kwh	1.19×10^5 kwh	9000 Therms 1.48×10^6 kwh			17×10^5 kwh 27×10^9 Btu	1.8×10^5 kwh 10×10^9 Btu	1.5×10^5 kwh 12×10^9 Btu	1.5×10^5 kwh 4.7×10^9 Btu	22,000 kwh	22,000 kwh	22,000 kwh	1.3×10^5 kwh	1.3×10^5 kwh
CONCRETE (CU YDS)	61,600	166,000	160,000	19,300		3100	3520	3400	3560	105,000	105,000	105,000	105,000	105,000
STEEL (TONS)	5400	17,400	18,500	1270		2600	2860	2780	3040	9600	9600	9600	10,000	10,000
CHEMICALS (LBS/DAY)	Polymer-2100 Lime-2.1×10^6 Na_2CO_3-84,000 Cl_2-42,000 C-338,500 NaCl-1×10^5 CO_2-2.65×10^6 Zeolite-88,400						19,170-26,830	4500-5500	1170-5830	1170-5830	1170-5830	1170-5830	17,170-[illegible]	17,170-[illegible]
LAND (ACRES)		190	80			2100-2900	410-550	410-550	270-320	1320-1560	6000-27,000	26-36	820-1120	30-40
LABOR (MAN YRS/YR)	280	410	570			540-720	384-492	267-354	310-360	200-600	132-178	131-178	250-290	250-280
OUTPUTS - BOD (MG/L)	130	10-30	1											
(LBS/DAY)	1.04×10^6	$.8-3 \times 10^5$	8400											
SUSPENDED SOLIDS (MG/L)	80	10-30	.3											
(LBS/DAY)	6.4×10^5	$.8-3 \times 10^5$	2500											
NUTRIENTS: P (MG/L)	14.3	10	1											
(LBS/DAY)	114,000	84,000	8400			$8-11.5 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$
N (MG/L)	32	25	.5-1											
(LBS/DAY)	2.56×10^5	2.1×10^5	4200-8400							$.8-1 \times 10^5$	$.8-1 \times 10^5$	$.8-1 \times 10^5$	$.8-1 \times 10^5$	$.8-1 \times 10^5$
HEAVY METALS (LBS/DAY)		2500-50,000		2500-50,000		2500-50,000	$.13-3.3 \times 10^4$	$.13-3.3 \times 10^4$	$.13-3.3 \times 10^4$	$.15-3.3 \times 10^4$	$.15-3.3 \times 10^4$	$.15-3.3 \times 10^4$	$.15-3.3 \times 10^4$	$.15-3.3 \times 10^4$
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=250-400 SO_2=440-670 HCl=80-120 NO_x=2500-3900 Particulates=4400-7000							
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	1.08×10^6	1.25×10^6	4.54×10^6			3.63×10^6	699,000	692,000	524,000	1.4×10^6	1.4×10^6	1.4×10^6	1.4×10^6	1.4×10^6
SOLID WASTE (CU FT/YR)			1.78×10^6				$12-18 \times 10^3$	3000-4600	800-3800	800-3800	800-3800		$9-12 \times 10^3$	$9-12 \times 10^3$
NUISANCE - ODOR	Potential	Potential	Controlled			None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE								Above Average						
TRAFFIC				69		91	17.5	17.5	13.1	35	35	.3	35	1
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($ x 10^6)	117	143-150	238	1.3		32-43	34-47	50-68	110-150	44-52	7.1-9.7	16.1-21.8	36-48	35-47
RUNNING TOTAL CAPITAL ($ x 10^6)	117	260-267	498-505	499-506		531-549	565-596	581-617	641-699	575-601	538-559	547-571	567-597	566-596
LAND ($)		190,000	80,000			2.1-2.[illegible]	$4.1-5.5 \times 10^5$	$4.1-5.5 \times 10^5$	$2.7-3.7 \times 10^5$	$1.32-1.54 \times 10^6$	$6-27 \times 10^6$	56,000-[illegible]	$.82-1.1 \times 10^6$	30,000-40,000
RUNNING GRAND TOTAL ($ x 10^6)	117	260-267	498-505	499-506		533-552	567-600	583-621	643-702	578-606	546-589	549-547	570-601	568-599
OPERATING (¢/1000 GAL)	2.0	1.0	12.6	.5		3.4-4.6	4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	1.7-2.4	.22-.3	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.7	4.6-4.9	7.7	.04		1.1-1.5	1.1-1.5	1.6-2.2	3.6-4.8	1.5-1.7	.4-1.2	.52-.7	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	5.7	5.6-5.9	20.3	.5		4.5-6.1	5.5-8.4	4.6-6.9	7.2-9.9	4.6-5.8	2.1-3.6	.7-1.0	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	5.7	11.3-11.5	31.6-31.8	32.1-32.3		36.6-38.4	42.1-46.8	41.2-45.3	43.8-48.3	41.2-44.2	38.7-42	37.3-39.4	41-45.3	40.5-44.9

Tertiary Treatment with Centrifugation-
Incineration of Chemical Sludge - 1000 MGD

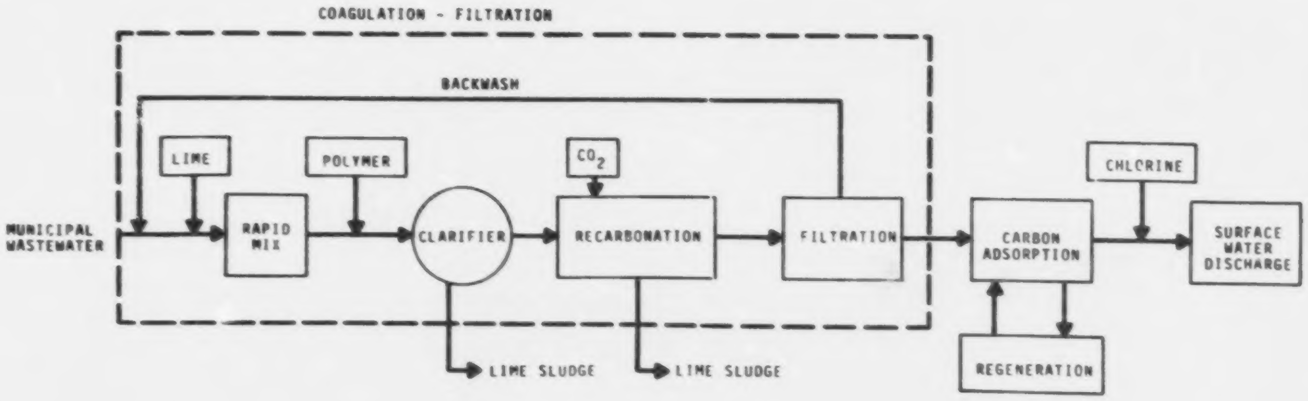
PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 9 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY Activated Sludge	TERTIARY Clarification Carbon Sorption Zeolite	LIQUID DISPOSAL Surface Water	UNIT OPERATION	12	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY	FLOTATION		FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION	FLOTATION
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	40,000 kwh	1.19×10^5 kwh	9000 Therms 1.48×10^6 kwh			[illegible] kwh 49×10^9 Btu	1.8×10^5 kwh 10×10^9 Btu	1.5×10^5 kwh 12×10^9 Btu	1.5×10^5 kwh 4.7×10^9 Btu	22,000 kwh	22,000 kwh	22,000 kwh	1.3×10^5 kwh	1.3×10^5 kwh
CONCRETE (CU YDS)	61,600	166,000	160,000	19,300		4350	3520	3400	3560	105,000	105,000	105,000	105,000	105,000
STEEL (TONS)	5400	17,400	18,500	1270		3700	2860	2780	3040	9600	9600	9600	10,000	10,000
CHEMICALS (LBS/DAY)	Polymer-2100 Lime-6.3×10^5 Na_2CO_3-84,000 CO_2-2.6 C-338,500 NaCl-100,000 Zeolite-88,400 Cl_2-82,000						[illegible]	4500-5500	1170-5830	1170-5830	1170-5830	1170-5830	[illegible]	[illegible]
LAND (ACRES)		190	80			1300-1700	410-550	410-550	270-370	1370-1540	6000-27,000	26-36	820-1120	30-40
LABOR (MAN YRS/YR)	280	410	570			880-1200	384-492	267-354	310-360	200-600	132-178	131-178	250-290	250-280
OUTPUTS - BOD (MG/L)	130	10-30	1											
(LBS/DAY)	1.04×10^6	$.8-3 \times 10^5$	8400											
SUSPENDED SOLIDS (MG/L)	80	10-30	13											
(LBS/DAY)	6.4×10^5	$.8-3 \times 10^5$	2500											
NUTRIENTS: P (MG/L)	14.3	10	1											
(LBS/DAY)	114,000	84,000	8400			$16-23 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$	$5-7 \times 10^4$
N (MG/L)	32	25	.5-1											
(LBS/DAY)	2.56×10^5	2.1×10^5	4200-8400							$.8-1 \times 10^5$	$.8-1 \times 10^5$	$.8-1 \times 10^5$	$.8-1 \times 10^5$	$.8-1 \times 10^5$
HEAVY METALS (LBS/DAY)		2500-50,000		2500-50,000		2500-50,000	$.13-3.3 \times 10^4$	$.13-3.3 \times 10^4$	$.13-3.3 \times 10^4$	$.15-3.3 \times 10^4$	$.15-3.3 \times 10^4$	$.15-3.3 \times 10^4$	$.15-3.3 \times 10^4$	$.15-3.3 \times 10^4$
ATMOSPHERIC EMISSIONS (LBS/DAY)							Metals=250-400 NO_x=2500-3900	SO_2=440-670 Particulates=4400-7000	HCl=80-120					
SLUDGES-% SOLIDS	5	1	1-5			100	100	100	100	25-50	6-8	6-8	20-30	20-30
TOTAL DRY WT. (LBS/DAY)	1.08×10^6	1.25×10^6	8.11×10^6			2.16×10^6	699,000	699,000	524,000	1.4×10^6	1.4×10^6	1.4×10^6	1.4×10^6	1.4×10^6
SOLID WASTE (CU FT/YR)			8.2×10^5				$12-18 \times 10^3$	3000-3600	800-3800	800-3800	800-3800		$9-12 \times 10^3$	$9-12 \times 10^3$
NUISANCE - ODOR	Potential	Potential	Controlled			None	None	None	None	Potential	Potential	None	Potential	Potential
NOISE								Above Average						
TRAFFIC				32		54	17.5	17.5	13.1	35	35	.3	35	1
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($ x 10^6)	117	143-150	238	1.3		74-101	34-47	50-68	110-150	44-52	7.1-9.7	16.1-21.8	36-48	35-47
RUNNING TOTAL CAPITAL ($ x 10^6)	117	260-267	498-505	499-506		573-607	607-654	623-675	683-757	617-659	580-617	589-629	609-655	608-654
LAND ($)		190,000	80,000			$1.3-1.7 \times 10^6$	$4.1-5.5 \times 10^5$	$4.1-5.5 \times 10^5$	$2.7-3.7 \times 10^5$	$1.37-1.54 \times 10^6$	$6-27 \times 10^6$	28,000-36,000	$.82-1.1 \times 10^6$	30,000-40,000
RUNNING GRAND TOTAL ($ x 10^6)	117	260-267	498-505	499-506		574-609	608-657	624-678	684-759	619-663	587-646	590-631	611-658	609-656
OPERATING (¢/1000 GAL)	2.0	1.0	12.6	.5		5.6-9.4	4.4-6.9	2.95-4.65	3.6-5.1	3.1-4.1	1.7-2.4	.22-.3	3.2-5.3	2.8-5.0
10% AMORTIZED (¢/1000 GAL)	3.7	4.6-4.8	7.7	.04		2.4-3.3	1.1-1.5	1.6-2.2	3.6-4.8	1.5-1.7	.4-1.2	.52-.7	1.2-1.6	1.1-1.5
TOTAL OPERATING (¢/1000 GAL)	5.7	5.6-5.8	20.3	.5		8.0-12.7	5.5-8.4	4.6-6.9	7.2-9.5	4.6-5.8	2.1-3.6	.7-1.0	4.4-6.9	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	5.7	11.3-11.5	31.6-31.8	32.1-32.3		40.1-45	45.6-53.4	44.7-51.9	47.3-54.9	44.7-50.8	44.4-52.8	40.8-46	44.5-51.9	44-51.5

Tertiary Treatment with Centrifugation-
Recalcination of Chemical Sludge - 1000 MGD

PROCESS PROFILE SHEETS FOR TREATMENT STRATEGY # 10

Physical-Chemical Treatment


COAGULATION - FILTRATION
BACKWASH
MUNICIPAL WASTEWATER
LIME
RAPID MIX
POLYMER
CLARIFIER
CO_2
RECARBONATION
FILTRATION
LIME SLUDGE
LIME SLUDGE
CARBON ADSORPTION
REGENERATION
CHLORINE
SURFACE WATER DISCHARGE

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 10 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	9	1	2	3	4	5	6	7	8
	None	Coagulation Filtration	Carbon Sorption	Surface Water	THICKENING:	GRAVITY								
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		5480 kwh	90 therms 4260 kwh			4867 kwh 291 x10^6 Btu								
CONCRETE (CU YDS)		760	215	41		64								
STEEL (TONS)		224	80	2.7		90								
CHEMICALS (LBS/DAY)		Lime-21,000 CO_2-26,500	Polymer-21 C-3885	Cl_2-420										
LAND (ACRES)		8	1			32-43								
LABOR (MAN YRS/YR)		10.6	4.5			9.9-13.5								
OUTPUTS - BOD (MG/L)		57	8											
(LBS/DAY)		4788	672											
SUSPENDED SOLIDS (MG/L)		65	7											
(LBS/DAY)		5460	588											
NUTRIENTS: P (MG/L)		1.5	.13											
(LBS/DAY)		125	11			850-1200								
N (MG/L)		30	27											
(LBS/DAY)		2500	2250							DOES				
HEAVY METALS (LBS/DAY)		Negligible				40-830				NOT				
ATMOSPHERIC EMISSIONS (LBS/DAY)														
SLUDGES-% SOLIDS		4				100				APPLY				
TOTAL DRY WT. (LBS/DAY)		68,700				54,960								
SOLID WASTE (CU FT/YR)			16,000											
NUISANCE - ODOR						None								
NOISE														
TRAFFIC				.6		1.4								
SAFETY (INJURIES/10^6 MAN-HRS)						28.5								
COSTS - CAPITAL ($ x 10^6)		2	2.1	.043		2.6-3.5								
RUNNING TOTAL CAPITAL ($ x 10^6)		2	4.1	4.1		6.7-7.6								
LAND ($)		8000	1000			32-43x10^3								
RUNNING GRAND TOTAL ($ x 10^6)		2	4.1	4.1		6.7-7.6								
OPERATING (¢/1000 GAL)		7.7	6.8	.9		5.1-9.7								
10% AMORTIZED (¢/1000 GAL)		6.4	6.8	.1		8.4-11.3								
TOTAL OPERATING (¢/1000 GAL)		14.1	13.6	1		13.5-21.0								
RUNNING TOTAL (¢/1000 GAL)		14.1	27.7	28.7		42.2-49.7								

Physical-Chemical Treatment with Filtration-Incineration of Chemical Sludge - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 10 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	10	1	2	3	4	5	6	7	8
	None	Coagulation Filtration	Carbon Sorption	Surface Water	THICKENING:	GRAVITY								
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		5480 kwh	90 Therms 4200 kwh			[illegible]x10^6 kwh 888x10^6 Btu								
CONCRETE (CU YDS)		760	215	41		101								
STEEL (TONS)		224	80	2.7		162								
CHEMICALS (LBS/DAY)		Polymer-21 C-3385	Lime-6300 CO_2-26,300	Cl_2-420										
LAND (ACRES)		8	1			24-32								
LABOR (MAN YRS/YR)		10.6	4.5			22.5-30.4								
OUTPUTS - BOD (MG/L)		57	8											
(LBS/DAY)		4788	672											
SUSPENDED SOLIDS (MG/L)		65	7											
(LBS/DAY)		5460	588											
NUTRIENTS: P (MG/L)		1.5	.13											
(LBS/DAY)		125	11			1700-2400								
N (MG/L)		30	27											
(LBS/DAY)		2500	2250						DOES					
HEAVY METALS (LBS/DAY)			Negligible			40-830								
ATMOSPHERIC EMISSIONS (LBS/DAY)									NOT					
SLUDGES-% SOLIDS		4				100			APPLY					
TOTAL DRY WT. (LBS/DAY)		148,000				40,300								
SOLID WASTE (CU FT/YR)			6380											
NUISANCE - ODOR			Controlled			None								
NOISE														
TRAFFIC				.33		1								
SAFETY (INJURIES/10^6 MAN-HRS)						28.5								
COSTS - CAPITAL (\$ x 10^6)		2	2.1	.043		2.9-3.9								
RUNNING TOTAL CAPITAL (\$ x 10^6)		2	4.1	4.1		7-8								
LAND (\$)		8000	1000			24-32x10^3								
RUNNING GRAND TOTAL (\$ x 10^6)		2	4.1	4.1		7-8								
OPERATING (¢/1000 GAL)		7.7	6.8	.9		8.6-20.7								
10% AMORTIZED (¢/1000 GAL)		6.4	6.8	.1		9.4-12.6								
TOTAL OPERATING (¢/1000 GAL)		14.1	13.6	1		18-33.3								
RUNNING TOTAL (¢/1000 GAL)		14.1	27.7	28.[illegible]		46.7-62								

Physical-Chemical Treatment with Filtration-
Recalcination of Chemical Sludge - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 10 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	11	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY								
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
	None	Coagulation Filtration	Carbon Sorption	Surface Water	DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		5480 kWh	90 Therms 4200 kWh			2635 kWh 291×10^6 Btu								
CONCRETE (CU YDS)		760	215	41		63								
STEEL (TONS)		224	80	2.7		53								
CHEMICALS (LBS/DAY)		Lime-21,000 CO_2-26,500	Polymer-21 C-3385	Cl-420										
LAND (ACRES)		8	1			31-43								
LABOR (MAN YRS/YR)		10.6	4.5			9.6-12.7								
OUTPUTS - BOD (MG/L)		57	8											
(LBS/DAY)		4788	672											
SUSPENDED SOLIDS (MG/L)		65	7											
(LBS/DAY)		5460	588											
NUTRIENTS: P (MG/L)		1.5	.13											
(LBS/DAY)		125	11			850-1200								
N (MG/L)		30	27											
(LBS/DAY)		2500	2250						DOES					
HEAVY METALS (LBS/DAY)		Negligible				40-830			NOT					
ATMOSPHERIC EMISSIONS (LBS/DAY)														
SLUDGES-% SOLIDS		4				100			APPLY					
TOTAL DRY WT. (LBS/DAY)		68,700				54,960								
SOLID WASTE (CU FT/YR)			16,000											
NUISANCE - ODOR				Controlled		None								
NOISE														
TRAFFIC				.6		1.4								
SAFETY (INJURIES/10^6 MAN-HRS)						28.5								
COSTS - CAPITAL ($ x 10^6)		2	2.1	.04		1.6-2.1								
RUNNING TOTAL CAPITAL ($ x 10^6)		2	4.1	4.1		5.7-6.2								
LAND ($)		8000	1000			$31\text{-}43 \times 10^3$								
RUNNING GRAND TOTAL ($ x 10^6)		2	4.1	4.1		5.7-6.2								
OPERATING (¢/1000 GAL)		7.7	6.8	.9		4-5.5								
10% AMORTIZED (¢/1000 GAL)		6.4	6.8	.1		5.2-6.9								
TOTAL OPERATING (¢/1000 GAL)		14.1	13.6	1		9.2-12.4								
RUNNING TOTAL (¢/1000 GAL)		14.1	27.7	28.7		37.9-41.1								

Physical-Chemical Treatment with Centrifugation-
Incineration of Chemical Sludge - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 10 AT A FLOW RATE OF 10 MGD

	LIQUID TREATMENT PRIMARY	 SECONDARY	 TERTIARY	 LIQUID DISPOSAL	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	CHEMICAL SLUDGE OPTION 12 GRAVITY CENTRIFUGE RECALCINATION REFUSE-LANDFILL	ORGANIC SLUDGE TREATMENT OPTIONS 1 CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	 2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	 3 PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	 4 DIGESTION SAND DRYING LANDFILL	 5 DIGESTION LAND SPREADING	 6 DIGESTION OCEAN DUMPING	 7 DIGESTION VACUUM FILTRATION LANDFILL	 8 DIGESTION VACUUM FILTRATION OCEAN DUMPING
	None	Coagulation Filtration	Carbon Sorption	Surface Water										
INPUTS - ENERGY (UNITS/DAY)		5480 kwh	90 Therms 4200 kwh			1056 kwh 888x10^6 Btu								
CONCRETE (CU YDS)		760	215	41		99								
STEEL (TONS)		224	80	27		83								
CHEMICALS (LBS/DAY)		Polymer-21 C-3385	Lime-6300 CO$_2$-26,500	Cl$_2$-420										
LAND (ACRES)		8	1			23-32								
LABOR (MAN YRS/YR)		10.6	4.5			20-28								
OUTPUTS - BOD (MG/L)		57	8											
(LBS/DAY)		4788	672											
SUSPENDED SOLIDS (MG/L)		65	7											
(LBS/DAY)		5460	588											
NUTRIENTS: P (MG/L)		1.5	.13											
(LBS/DAY)		125	11			1700-2400								
N (MG/L)		30	27											
(LBS/DAY)		2500	2250							DOES				
HEAVY METALS (LBS/DAY)		Negligible				40-830				NOT				
ATMOSPHERIC EMISSIONS (LBS/DAY)														
SLUDGES-% SOLIDS		4				100				APPLY				
TOTAL DRY WT. (LBS/DAY)		148,000				40,300								
SOLID WASTE (CU FT/YR)			6380											
NUISANCE - ODOR				Controlled		None								
NOISE														
TRAFFIC				.33		1								
SAFETY (INJURIES/10^6 MAN-HRS)						28.5								
COSTS - CAPITAL ($ x 10^6)		2	2.1	.043		2.3-3.2								
RUNNING TOTAL CAPITAL ($ x 10^6)		2	4.1	4.1		6.4-7.3								
LAND ($)		8000	1000			23-32x10^3								
RUNNING GRAND TOTAL ($ x 10^6)		2	4.1	4.1		6.4-7.3								
OPERATING (¢/1000 GAL)		7.7	6.8	.9		9.5-16.6								
10% AMORTIZED (¢/1000 GAL)		6.4	6.8	.1		7.5-10.4								
TOTAL OPERATING (¢/1000 GAL)		14.1	13.6	1		17-27								
RUNNING TOTAL (¢/1000 GAL)		14.1	27.7	28.7		45.7-55.7								

Physical-Chemical Treatment with Centrifugation-
Recalcination of Chemical Sludge - 10 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 10 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY None	SECONDARY Coagulation Filtration	TERTIARY Carbon Sorption	LIQUID DISPOSAL Surface Water	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	9 GRAVITY VACUUM FILTRATION INCINERATION LANDFILL	1 CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 DIGESTION SAND DRYING LANDFILL	5 DIGESTION LAND SPREADING	6 DIGESTION OCEAN DUMPING	7 DIGESTION VACUUM FILTRATION LANDFILL	8 DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		16,000 kwh	900 Therms 14,400 kwh			48,675 kwh 2.9x10^9 Btu								
CONCRETE (CU YDS)		8300	4800	2120		275								
STEEL (TONS)		710	490	140		670								
CHEMICALS (LBS/DAY)		Polymer-210 Lime 7.[illegible]x10^5 Cl2-4200 C-33[illegible]40 CO2-2.85x10^5												
LAND (ACRES)		27	3			315-427								
LABOR (MAN YRS/YR)		49	29			63-85								
OUTPUTS - BOD (MG/L)		57	8											
(LBS/DAY)		47,880	6720											
SUSPENDED SOLIDS (MG/L)		65	7											
(LBS/DAY)		54,600	5880											
NUTRIENTS: P (MG/L)		1.5	.13											
(LBS/DAY)		1250	110			8500-12,000								
N (MG/L)		30	27											
(LBS/DAY)		25,000	22,500								DOES			
HEAVY METALS (LBS/DAY)			Negligible			400-8300					NOT			
ATMOSPHERIC EMISSIONS (LBS/DAY)														
SLUDGES-% SOLIDS		4				100					APPLY			
TOTAL DRY WT. (LBS/DAY)		687,000				349,600								
SOLID WASTE (CU FT/YR)			160,000											
NUISANCE - ODOR			Controlled			None								
NOISE														
TRAFFIC				6.2		13.7								
SAFETY (INJURIES/10^6 MAN-HRS)						<1								
COSTS - CAPITAL ($ x 10^6)		10.2	13.8	.13		8.2-11.1								
RUNNING TOTAL CAPITAL ($ x 10^6)		10.2	24	24.1		32.3-35.2								
LAND ($)		27,000	3000			3.15-4.27x10^5								
RUNNING GRAND TOTAL ($ x 10^6)		10.2	24	24.1		32.6-35.6								
OPERATING (¢/1000 GAL)		5.2	5.4	.7		5-9.6								
10% AMORTIZED (¢/1000 GAL)		3.3	4.4	.04		2.7-3.7								
TOTAL OPERATING (¢/1000 GAL)		8.5	9.8	.7		7.7-13.3								
RUNNING TOTAL (¢/1000 GAL)		8.5	18.3	19.0		26.7-32.3								

Physical-Chemical Treatment with Filtration-
Incineration of Chemical Sludge - 100 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 10 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY None	SECONDARY Coagulation Filtration	TERTIARY Carbon Sorption	LIQUID DISPOSAL Surface Water	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	10 GRAVITY VACUUM FILTRATION RECALCINATION REUSE-LANDFILL	1 CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 DIGESTION SAND DRYING LANDFILL	5 DIGESTION LAND SPREADING	6 DIGESTION OCEAN DUMPING	7 DIGESTION VACUUM FILTRATION LANDFILL	8 DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		16,000 kwh	900 Therms 14,400 kwh			1.4×10^{5} kwh 1.4×10^{9} Btu								
CONCRETE (CU YDS)		8300	4800	2120		434								
STEEL (TONS)		710	490	140		1059								
CHEMICALS (LBS/DAY)		Polymer-210 C-33,850	Lime-63,000 CO_2-2.65×10^{5}	Cl_2-4200										
LAND (ACRES)		27	3			240-320								
LABOR (MAN YRS/YR)		69	29			121-164								
OUTPUTS - BOD (MG/L)		57	8											
(LBS/DAY)		47,880	6720											
SUSPENDED SOLIDS (MG/L)		65	7											
(LBS/DAY)		54,600	5880											
NUTRIENTS: P (MG/L)		1.5	.13											
(LBS/DAY)		1250	110			17,000-24,000								
N (MG/L)		30	27											
(LBS/DAY)		25,000	22,500											
HEAVY METALS (LBS/DAY)			Negligible			400-8300				DOES NOT APPLY				
ATMOSPHERIC EMISSIONS (LBS/DAY)														
SLUDGES-% SOLIDS		6				100								
TOTAL DRY WT. (LBS/DAY)		2.48×10^{6}				403,000								
SOLID WASTE (CU FT/YR)			63,800											
NUISANCE - ODOR			Controlled			None								
NOISE														
TRAFFIC				3.3		10								
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($ x 10^6)		10.2	13.8	.13		14.6-19.7								
RUNNING TOTAL CAPITAL ($ x 10^6)		10.2	24	24.1		38.7-43.8								
LAND ($)		27,000	3000			2.4-3.2 $\times 10^{5}$								
RUNNING GRAND TOTAL ($ x 10^6)		10.2	24	24.1		38.9-44.1								
OPERATING (¢/1000 GAL)		5.2	5.4	.7		9.3-21.4								
10% AMORTIZED (¢/1000 GAL)		3.3	4.4	.04		4.8-6.4								
TOTAL OPERATING (¢/1000 GAL)		8.5	9.8	.7		14.1-27.8								
RUNNING TOTAL (¢/1000 GAL)		8.5	18.3	19.0		33.1-46.8								

Physical-Chemical Treatment with Filtration-
Recalcination of Chemical Sludge - 100 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 10 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	11	1	2	3	4	5	6	7	8
	None	Coagulation Filtration	Carbon Sorption	Surface Water	THICKENING:	GRAVITY								
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		16,000 kwh	900 Therms 14,400 kwh			26,250 kwh 2.9×10^9 Btu								
CONCRETE (CU YDS)		8300	4800	2120		320								
STEEL (TONS)		710	490	140		424								
CHEMICALS (LBS/DAY)		Polymer-210 C-33440	Lime 2.1×10^5 CO_2-1.65×10^5	Cl_2-4200										
LAND (ACRES)		27	3			310-430								
LABOR (MAN YRS/YR)		49	29			65.5-88.6								
OUTPUTS - BOD (MG/L)		57	8											
(LBS/DAY)		47,880	6720											
SUSPENDED SOLIDS (MG/L)		65	7											
(LBS/DAY)		54,600	5880											
NUTRIENTS: P (MG/L)		1.5	.13											
(LBS/DAY)		1250	110			8500-12,000								
N (MG/L)		30	27											
(LBS/DAY)		25,000	22,500						DOES					
HEAVY METALS (LBS/DAY)		Negligible				400-8300								
ATMOSPHERIC EMISSIONS (LBS/DAY)									NOT					
SLUDGES-% SOLIDS		4				100			APPLY					
TOTAL DRY WT. (LBS/DAY)		687,000				549,600								
SOLID WASTE (CU FT/YR)			160,000											
NUISANCE - ODOR			Controlled			None								
NOISE														
TRAFFIC				6.2		13.7								
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($\$ \times 10^6$)		10.2	13.8	.13		6.2-8.5								
RUNNING TOTAL CAPITAL ($\$ \times 10^6$)		10.2	24	24.1		30.3-32.6								
LAND ($)		27,000	3000			3.2-4.24×10^5								
RUNNING GRAND TOTAL ($\$ \times 10^6$)		10.2	24	24.1		30.6-33.1								
OPERATING (¢/1000 GAL)		5.2	5.4	.7		4-5.4								
10% AMORTIZED (¢/1000 GAL)		3.3	4.4	.04		2.1-2.7								
TOTAL OPERATING (¢/1000 GAL)		8.5	9.8	.7		6.1-8.1								
RUNNING TOTAL (¢/1000 GAL)		8.5	18.3	19.0		25.1-27.1								

Physical-Chemical Treatment with Centrifugation-
Incineration of Chemical Sludge - 100 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 10 AT A FLOW RATE OF 100 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	12	1	2	3	4	5	6	7	8
	None	Coagulation Filtration	Carbon Sorption	Surface Water	THICKENING:	GRAVITY								
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		16,000 kwh	900 Therms 14,400 kwh			$1.1x10^5$ kwh $8.9x10^9$ Btu								
CONCRETE (CU YDS)		8300	4800	2120		506								
STEEL (TONS)		710	490	140		670								
CHEMICALS (LBS/DAY)	Polymer-210 Lime-63,000 Cl_2-4800 C-11,250 CO_2-$2.75x10^5$													
LAND (ACRES)		27	3			230-320								
LABOR (MAN YRS/YR)		49	29			122-165								
OUTPUTS - BOD (MG/L)		57	8											
(LBS/DAY)		47,880	6720											
SUSPENDED SOLIDS (MG/L)		65	7											
(LBS/DAY)		54,600	5880											
NUTRIENTS: P (MG/L)		1.5	.13			17,000-24,000								
(LBS/DAY)		1250	110											
N (MG/L)		30	27											
(LBS/DAY)		25,000	22,500											
HEAVY METALS (LBS/DAY)		Negligible				400-8300			DOES					
ATMOSPHERIC EMISSIONS (LBS/DAY)									NOT					
SLUDGES-% SOLIDS		4				100			APPLY					
TOTAL DRY WT. (LBS/DAY)		$1.48x10^6$				403,000								
SOLID WASTE (CU FT/YR)			63,800											
NUISANCE - ODOR			Controlled			None								
NOISE														
TRAFFIC				3.3		10								
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($ x 10^6)		10.2	13.8	.13		10.1-13.7								
RUNNING TOTAL CAPITAL ($ x 10^6)		10.2	24	24.1		34.2-37.8								
LAND ($)		27,000	3000			$2.3-3.2x10^5$								
RUNNING GRAND TOTAL ($ x 10^6)		10.2	24	24.1		34.4-38.1								
OPERATING (¢/1000 GAL)		5.2	5.4	.7		10.2-17.3								
10% AMORTIZED (¢/1000 GAL)		3.3	4.4	.04		3.3-4.5								
TOTAL OPERATING (¢/1000 GAL)		8.5	9.8	.7		13.5-21.8								
RUNNING TOTAL (¢/1000 GAL)		8.5	18.3	19.0		32.5-40.8								

Physical-Chemical Treatment with Centrifugation-
Recalcination of Chemical Sludge - 100 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 10 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY None	SECONDARY Coagulation Filtration	TERTIARY Carbon Sorption	LIQUID DISPOSAL Surface Water	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	9 GRAVITY VACUUM FILTRATION INCINERATION LANDFILL	1 CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	2 CHEMICAL CENTRIFUGE INCINERATION LANDFILL	3 PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	4 DIGESTION SAND DRYING LANDFILL	5 DIGESTION LAND SPREADING	6 DIGESTION OCEAN DUMPING	7 DIGESTION VACUUM FILTRATION LANDFILL	8 DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		$1.6\text{x}10^5$ kwh	9000 Therms $1.46\text{x}10^6$ kwh			$4.9\text{x}10^5$ kwh $29\text{x}10^9$ Btu								
CONCRETE (CU YDS)		83,000	48,000	19,300		2700								
STEEL (TONS)		7000	4800	1270		6500								
CHEMICALS (LBS/DAY)		Polymer-2100 C-336,500	Lime-$2.1\text{x}10^6$ CO_2-$2.65\text{x}10^5$	Cl_2-42,000										
LAND (ACRES)		270	30			3150-4270								
LABOR (MAN YRS/YR)		690	290			630-850								
OUTPUTS - BOD (MG/L)		57	8											
(LBS/DAY)		478,800	672,000											
SUSPENDED SOLIDS (MG/L)		65	7											
(LBS/DAY)		546,000	58,800											
NUTRIENTS: P (MG/L)		1.5	.13											
(LBS/DAY)		12,500	1100			$8.5\text{-}12\text{x}10^4$								
N (MG/L)		30	27											
(LBS/DAY)		250,000	225,000							DOES				
HEAVY METALS (LBS/DAY)			Negligible			$4\text{-}8.3\text{x}10^4$								
ATMOSPHERIC EMISSIONS (LBS/DAY)										NOT				
SLUDGES-% SOLIDS						100				APPLY				
TOTAL DRY WT. (LBS/DAY)		$6.87\text{x}10^6$				$5.5\text{x}10^6$								
SOLID WASTE (CU FT/YR)			$1.6\text{x}10^6$											
NUISANCE - ODOR			Controlled			None								
NOISE														
TRAFFIC				62		137								
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL (\$ x 10^6)		102	138	1.3		82-111								
RUNNING TOTAL CAPITAL (\$ x 10^6)		102	240	241		325-354								
LAND (\$)		270,000	30,000			$3.15\text{-}4.27\text{x}10^6$								
RUNNING GRAND TOTAL (\$ x 10^6)		102	240	241		328-358								
OPERATING (¢/1000 GAL)		5.2	5.4	.5		5-9.6								
10% AMORTIZED (¢/1000 GAL)		3.3	4.4	.04		2.7-3.7								
TOTAL OPERATING (¢/1000 GAL)		8.5	9.8	.5		7.7-13.3								
RUNNING TOTAL (¢/1000 GAL)		8.5	18.3	18.8		26.5-32.1								

Physical-Chemical Treatment with Filtration-Incineration of Chemical Sludge - 1000 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 10 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	10	1	2	3	4	5	6	7	8
	None	Coagulation Filtration	Carbon Sorption	Surface Water	THICKENING:	GRAVITY								
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		1.6x 10^5 kwh	9000 Therms [illegible]	[illegible]		[illegible] $x10^5$ kwh [illegible] $x10^9$ Btu								
CONCRETE (CU YDS)		83,000	48,000	19,300		4200								
STEEL (TONS)		7000	4800	1270		10,300								
CHEMICALS (LBS/DAY)		Polymer-2100 [illegible]	Lime 6.[illegible]$x10^5$ CO_2-[illegible]	Cl_2-42,000										
LAND (ACRES)		270	30			2400-3200								
LABOR (MAN YRS/YR)		490	290			1210-1640								
OUTPUTS - BOD (MG/L)		57	8											
(LBS/DAY)		478,800	67,200											
SUSPENDED SOLIDS (MG/L)		65	7											
(LBS/DAY)		546,000	58,800											
NUTRIENTS: P (MG/L)		1.5	.13											
(LBS/DAY)		12,500	1100			17-24x10^4								
N (MG/L)		30	27											
(LBS/DAY)		250,000	225,000						DOES					
HEAVY METALS (LBS/DAY)			Negligible			4-8.3x10^4								
ATMOSPHERIC EMISSIONS (LBS/DAY)									NOT					
SLUDGES % SOLIDS		4				100			APPLY					
TOTAL DRY WT. (LBS/DAY)		14.8x10^6				4.03x10^6								
SOLID WASTE (CU FT/YR)			638,000											
NUISANCE - ODOR			Controlled			None								
NOISE														
TRAFFIC				25		100								
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($ x 10^6)		102	138	1.3		146-197								
RUNNING TOTAL CAPITAL ($ x 10^6)		102	240	241		387-438								
LAND ($)		270,000	30,000			2.4-3.2x10^6								
RUNNING GRAND TOTAL ($ x 10^6)		102	240	241		389-441								
OPERATING (¢/1000 GAL)		5.2	5.4	.5		9.3-21.4								
10% AMORTIZED (¢/1000 GAL)		3.3	4.4	.04		4.8-6.4								
TOTAL OPERATING (¢/1000 GAL)		8.5	9.8	.5		14.1-27.8								
RUNNING TOTAL (¢/1000 GAL)		8.5	18.3	18.8		32.9-46.6								

Physical-Chemical Treatment with Filtration-Recalcination of Chemical Sludge - 1000 MGD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 10 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	11	1	2	3	4	5	6	7	8
	None	Coagulation Filtration	Carbon Sorption	Surface Water	THICKENING:	GRAVITY								
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		1.6×10^5 kwh	9000 Therms 1.44×10^5 kwh			2.6×10^6 kwh 29×10^9 Btu								
CONCRETE (CU YDS)		83,000	48,000	19,300		3100								
STEEL (TONS)		7000	4800	1270		4100								
CHEMICALS (LBS/DAY)	Polymer-2100 Lime 2.1×10^6 Cl_2-42,000 C-318,500 CO_2-2.65×10^6													
LAND (ACRES)		270	30			3100-4300								
LABOR (MAN YRS/YR)		490	290			619-837								
OUTPUTS - BOD (MG/L)		57	8											
(LBS/DAY)		478,800	67,200											
SUSPENDED SOLIDS (MG/L)		65	7											
(LBS/DAY)		546,000	58,800											
NUTRIENTS: P (MG/L)		1.5	.13											
(LBS/DAY)		12,500	1100			$8.5-12 \times 10^4$								
N (MG/L)		30	27											
(LBS/DAY)		250,000	225,000											
HEAVY METALS (LBS/DAY)			Negligible			$4-8.3 \times 10^4$			DOES					
ATMOSPHERIC EMISSIONS (LBS/DAY)									NOT					
SLUDGES-% SOLIDS						100			APPLY					
TOTAL DRY WT. (LBS/DAY)		6.87×10^6				5.5×10^6								
SOLID WASTE (CU FT/YR)			1.6×10^6											
NUISANCE - ODOR			Controlled			None								
NOISE														
TRAFFIC				62		137								
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($\$ \times 10^6$)		102	138	1.3		62-84								
RUNNING TOTAL CAPITAL ($\$ \times 10^6$)		102	240	241		303-325								
LAND ($)		270,000	30,000			$3.1-4.3 \times 10^6$								
RUNNING GRAND TOTAL ($\$ \times 10^6$)		102	240	241		307-330								
OPERATING (¢/1000 GAL)		5.2	5.4	.5		4-5.4								
10% AMORTIZED (¢/1000 GAL)		3.3	4.4	.04		2.1-2.7								
TOTAL OPERATING (¢/1000 GAL)		8.5	9.8	.5		6.1-8.1								
RUNNING TOTAL (¢/1000 GAL)		8.5	18.3	18.8		24.9-26.9								

Physical-Chemical Treatment with Centrifugation-
Incineration of Chemical Sludge - 1000 MGD

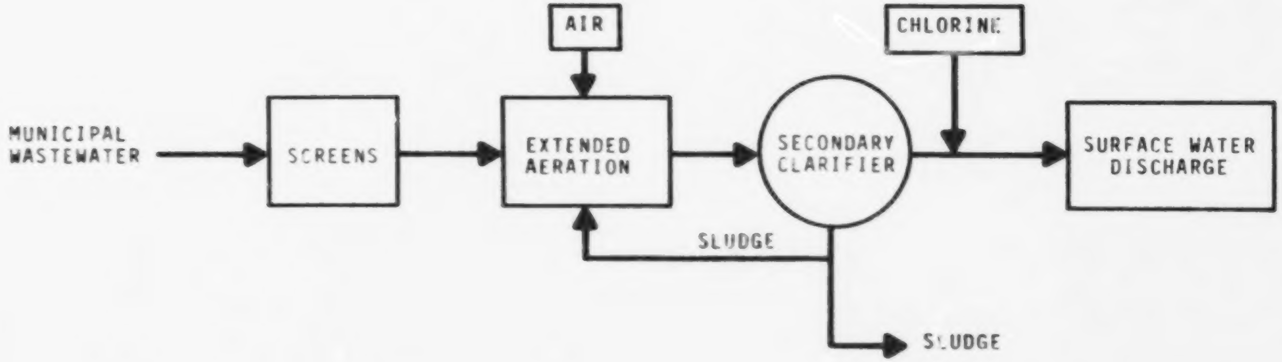
PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 10 AT A FLOW RATE OF 1000 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	12	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY								
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
	None	Coagulation Filtration	Carbon Sorption	Surface Water	DEWATERING:	CENTRIFUGE	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	RECALCINATION REUSE-LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		$1.6x10^5$ Kwh	9000 Therms $1.44x10^5$ Kwh			$11x10^5$ Kwh $69x10^9$ Btu								
CONCRETE (CU YDS)		83,000	48,000	19,300		4900								
STEEL (TONS)		7000	4800	1270		6500								
CHEMICALS (LBS/DAY)		Polymer-2100 C-33[illegible],500	Lime $6.3x10^5$ CO_2-$2.65x10^6$	Cl_2-42,000										
LAND (ACRES)		270	30			2300-3200								
LABOR (MAN YRS/YR)		490	290			1220-1650								
OUTPUTS - BOD (MG/L)		57	8											
(LBS/DAY)		478,800	67,200											
SUSPENDED SOLIDS (MG/L)		65	7											
(LBS/DAY)		546,000	58,800											
NUTRIENTS: P (MG/L)		1.5	.13											
(LBS/DAY)		12,500	1100			$17-24x10^4$								
N (MG/L)		30	27											
(LBS/DAY)		250,000	225,000							DOES				
HEAVY METALS (LBS/DAY)			Negligible			$4-8.3x10^4$								
ATMOSPHERIC EMISSIONS (LBS/DAY)										NOT				
SLUDGES-% SOLIDS		4				100				APPLY				
TOTAL DRY WT. (LBS/DAY)		$14.8x10^5$				$4.06x10^6$								
SOLID WASTE (CU FT/YR)			638,000											
NUISANCE - ODOR			Controlled			None								
NOISE														
TRAFFIC				25		100								
SAFETY (INJURIES/10^6 MAN-HRS)						41								
COSTS - CAPITAL ($ x 10^6)		102	138	1.3		101-137								
RUNNING TOTAL CAPITAL ($ x 10^6)		102	240	241		342-378								
LAND ($)		270,000	30,000			$2.3-3.2x10^6$								
RUNNING GRAND TOTAL ($ x 10^6)		102	240	241		344-381								
OPERATING (¢/1000 GAL)		5.2	5.4	.5		10.2-17.3								
10% AMORTIZED (¢/1000 GAL)		3.3	4.4	.04		3.3-4.5								
TOTAL OPERATING (¢/1000 GAL)		8.5	9.8	.5		13.5-21.8								
RUNNING TOTAL (¢/1000 GAL)		8.5	18.3	18.8		32.3-40.6								

Physical-Chemical Treatment with Centrifugation-
Recalcination of Chemical Sludge - 1000 MGD

PROCESS PROFILE SHEETS FOR TREATMENT STRATEGY # 11

Extended Aeration


MUNICIPAL WASTEWATER
SCREENS
AIR
EXTENDED AERATION
SECONDARY CLARIFIER
CHLORINE
SURFACE WATER DISCHARGE
SLUDGE
SLUDGE

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 11 AT A FLOW RATE OF 100,000 GPD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION		1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY								
					CONDITIONING:		CHEMICAL	CHEMICAL	PORTTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
	None	Extended Aeration		Surface Water	DEWATERING:	VACUUM FILTRATION	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
					DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		306 kwh												
CONCRETE (CU YDS)		8.5		10										
STEEL (TONS)		5.3		1										
CHEMICALS (LBS/DAY)				Cl_2-6.7										
LAND (ACRES)		1.6												
LABOR (MAN YRS/YR)		.66												
OUTPUTS - BOD (MG/L)		10-30												
(LBS/DAY)		8-25												
SUSPENDED SOLIDS (MG/L)		10-30												
(LBS/DAY)		8-25												
NUTRIENTS: P (MG/L)		7-10												
(LBS/DAY)		5.8-8.3												
N (MG/L)		15-25												
(LBS/DAY)		12.5-20.8								DOES				
HEAVY METALS (LBS/DAY)		.4-8.3		.4-8.3						NOT				
ATMOSPHERIC EMISSIONS (LBS/DAY)										APPLY				
SLUDGES-% SOLIDS		1-5												
TOTAL DRY WT. (LBS/DAY)		90												
SOLID WASTE (CU FT/YR)														
NUISANCE - ODOR		Negligible												
NOISE														
TRAFFIC				Negligible										
SAFETY (INJURIES/10^6 MAN-HRS)		21.3												
COSTS - CAPITAL ($ x 10^6)		.07-.1		.0045										
RUNNING TOTAL CAPITAL ($ x 10^6)		.07-.1		.075-.105										
LAND ($)		1600												
RUNNING GRAND TOTAL ($ x 10^6)		.072-.102		.077-.107										
OPERATING (¢/1000 GAL)		19.5		2										
10% AMORTIZED (¢/1000 GAL)		23-32.7		1.4										
TOTAL OPERATING (¢/1000 GAL)		42.5-52.2		3.4										
RUNNING TOTAL (¢/1000 GAL)		42.5-52.2		45.9-55.6										

Extended Aeration - 100,000 GPD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 11 AT A FLOW RATE OF 100,000 GPD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION		1	2	3	4	5	6	7	8
	None	Extended Aeration		Surface Water	THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	GRAVITY VACUUM FILTRATION INCINERATION LANDFILL	CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	CHEMICAL CENTRIFUGE INCINERATION LANDFILL	PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	DIGESTION SAND DRYING LANDFILL	DIGESTION LAND SPREADING	DIGESTION OCEAN DUMPING	DIGESTION VACUUM FILTRATION LANDFILL	DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		306 kwh												
CONCRETE (CU YDS)		8.3		10										
STEEL (TONS)		5.3		1										
CHEMICALS (LBS/DAY)				Cl_2-6.7										
LAND (ACRES)		1.6												
LABOR (MAN YRS/YR)		.66												
OUTPUTS - BOD (MG/L)		10-30												
(LBS/DAY)		8-25												
SUSPENDED SOLIDS (MG/L)		10-30												
(LBS/DAY)		8-25												
NUTRIENTS: P (MG/L)		7-10												
(LBS/DAY)		5.8-8.3												
N (MG/L)		15-25												
(LBS/DAY)		12.5-20.8												
HEAVY METALS (LBS/DAY)		.4-8.3		.4-8.3										
ATMOSPHERIC EMISSIONS (LBS/DAY)														
SLUDGES-% SOLIDS		1-5												
TOTAL DRY WT. (LBS/DAY)		90												
SOLID WASTE (CU FT/YR)														
NUISANCE - ODOR		Negligible												
NOISE														
TRAFFIC				Negligible										
SAFETY (INJURIES/10^6 MAN-HRS)		21.3												
COSTS - CAPITAL (\$ x 10^6)		.07-.1		.0045										
RUNNING TOTAL CAPITAL (\$ x 10^6)		.07-.1		.075-.105										
LAND (\$)		1600												
RUNNING GRAND TOTAL (\$ x 10^6)		.072-.102		.077-.107										
OPERATING (¢/1000 GAL)		19.5		2										
10% AMORTIZED (¢/1000 GAL)		23-32.7		1.4										
TOTAL OPERATING (¢/1000 GAL)		42.5-52.2		3.4										
RUNNING TOTAL (¢/1000 GAL)		42.5-52.2		45.9-55.6										

DOES
NOT
APPLY

Extended Aeration - 100,000 GPD

PROCESS PROFILE SHEET FOR TREATMENT STRATEGY # 11 AT A FLOW RATE OF 1 MGD

	LIQUID TREATMENT					CHEMICAL SLUDGE OPTION	ORGANIC SLUDGE TREATMENT OPTIONS							
							1	2	3	4	5	6	7	8
	PRIMARY None	SECONDARY Extended Aeration	TERTIARY	LIQUID DISPOSAL Surface Water	UNIT OPERATION THICKENING: CONDITIONING: DEWATERING: DISPOSAL:	GRAVITY VACUUM FILTRATION INCINERATION LANDFILL	CHEMICAL VACUUM FILTRATION INCINERATION LANDFILL	CHEMICAL CENTRIFUGE INCINERATION LANDFILL	PORTEOUS VACUUM FILTRATION INCINERATION LANDFILL	DIGESTION SAND DRYING LANDFILL	DIGESTION LAND SPREADING	DIGESTION OCEAN DUMPING	DIGESTION VACUUM FILTRATION LANDFILL	DIGESTION VACUUM FILTRATION OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)		960 kwh												
CONCRETE (CU YDS)		510		41										
STEEL (TONS)		42		2.7										
CHEMICALS (LBS/DAY)				Cl$_2$--67										
LAND (ACRES)		3.2												
LABOR (MAN YRS/YR)		2.6												
OUTPUTS - BOD (MG/L)		10-30												
(LBS/DAY)		80-250												
SUSPENDED SOLIDS (MG/L)		10-30												
(LBS/DAY)		80-250												
NUTRIENTS: P (MG/L)		7-10												
(LBS/DAY)		58-83												
N (MG/L)		15-25												
(LBS/DAY)		125-208								DOES				
HEAVY METALS (LBS/DAY)		4-83		4-83						NOT				
ATMOSPHERIC EMISSIONS (LBS/DAY)														
SLUDGES-% SOLIDS		1-5								APPLY				
TOTAL DRY WT. (LBS/DAY)		900												
SOLID WASTE (CU FT/YR)														
NUISANCE - ODOR		Negligible												
NOISE		Slight												
TRAFFIC				Negligible										
SAFETY (INJURIES/10^6 MAN-HRS)		19.6												
COSTS - CAPITAL ($ x 10^6)		.4-.6		.013										
RUNNING TOTAL CAPITAL ($ x 10^6)		.4-.6		.413-.61										
LAND ($)		3200												
RUNNING GRAND TOTAL ($ x 10^6)		.403-.603		.416-.61										
OPERATING (¢/1000 GAL)		8.3		1.1										
10% AMORTIZED (¢/1000 GAL)		13-19.4		.4										
TOTAL OPERATING (¢/1000 GAL)		21.3-27.7		1.5										
RUNNING TOTAL (¢/1000 GAL)		21.3-27.7		22.8-29.										

Extended Aeration - 1 MGD

COST ESTIMATION CONSIDERATIONS

It must be recognized that the profile comparisons constructed for this report contain cost data based on specific assumptions for pertinent unit cost factors. These factors will vary with location and time. This section of the report contains work sheets and example calculations which are included to enable the user to develop cost information more pertinent to his specific case.

CAPITAL COSTS

Capital costs for the eleven treatment strategies evaluated in this report are provided on the profile sheets. Specific estimates must be adjusted to correct for differences in design flow rate, national cost factors, local cost multipliers, and land values.

Cost changes due to variations in plant size can be approximated through use of the exponential rule. That is, if plant size changes by a factor of X, the cost will change by a factor of X^N where N varies from 0-1. The exact value for N is determined by the economies of scale one encounters when constructing larger facilities. That is, typically, unit costs decrease with size. The exponentional factor N has been found to average 0.6 for wastewater treatment facilities and equipment designed for plants with 100 MGD flow or less. Above 100 MGD, N approaches unity; that is, little or no economies of scale are realized in increasing plant size beyond 100 MGD.[13]

National cost factors refer to changes in overall price structure due to economic trends (e.g., recession, and inflation). These factors are frequently updated and published in Engineering News Record as the ENR Cost Index. Cost estimates can be updated by multiplying the base cost by the ratio of the current ENR index to the index that prevailed when the base cost was formulated. Costs presented in this report are given as 1973 dollars and are based on an ENR index of 169 using the 1967 base year. The EPA also publishes a Sewage Treatment Plant Construction Cost Index (STPCCI). This index is the preferred adjustment factor when available. Cost figures in this report are based on an STPCCI of 175.

Local cost multipliers are employed to adjust national average costs to figures reflecting the price structure likely to prevail at the location where the plant is to be built. Local cost multipliers are published in the Engineering News Record for major metropolitan areas in the United States.

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Land values vary greatly with the area of the country, and the proximity to urban areas. Location of a treatment facility should reflect consideration of land values and cost estimates must be adjusted accordingly. For the purposes of developing the data presented in the profile sheets in this report, a land value of $1000 per acre was assumed.

OPERATING COSTS

Operating costs may vary from the estimates provided in this report as a result of changes in costs for power, fuel, chemical, labor, transportation, supervision, and maintenance; or as result of selection of plant sizes other than those evaluated. The first step in refining operating costs is to adjust the levels of these inputs required for the flow rate under consideration. No adjustment is necessary if the design flow rate matches the rate evaluated on the profile sheet.

Adjustment factors vary with the parameter of concern. An exponential rule is approximated for operational and maintenance costs in general and chemicals, labor, and electrical power specifically. Thus quantity requirement estimation for plants designed at flows other than those evaluated in this report can be made by taking the ratio of the design rate and a rate presented in this report to a standard exponential. The value of the exponential should be 0.58 for labor and supervision, 0.55 for electrical, 1.0 for chemical, and 0.52 for operation and maintenance in general up to flow rates of 100 MGD.[13] All exponentials approach unity at flow rates greater than 100 MGD. Fuel and transportation costs are directly related to sludge volume and thus can be considered to have quantity multiplier exponentials close to one. Transportation costs are also dependent on the distance of travel required.

Once these adjustments in the quantity of inputs required are made, estimates can be made to reflect the actual operating and maintenance costs anticipated. The calculations for this phase of cost adjustment are straightforward since they involve only the use of the adjusted quantities and prevailing prices.

Total annual costs can be calculated by adding amortized capital costs to the operating and maintenance costs discussed above. These cost adjustment procedures are illustrated in the following example calculations. A blank worksheet is also provided at the end of this chapter.

EXAMPLE CALCULATIONS

Assumptions for Sample Calculation

Plant Type - Activated Sludge with Digestion and Landspreading of Sludge (Strategy #5, Sludge Option #5)

Flow Rate - 25 MGD

Prevailing Construction Index - STPCCI - 180

Local Multiplier - 1.1

Local Land Value - $1500/acre

Local Cost of Labor - $5.00/hr.

Local Cost of Power - 2¢/KWhr

Prevailing Cost of Chemicals - Chlorine - $0.05/lb.

Conditioning Polymer - $2.00/lb.

Transport Distance for Sludge - 60 miles round trip

Transport Cost for Sludge - $0.05/ton-mile (round trip basis)

Transport Distance for Effluent - Not Applicable

Transport Cost for Effluent - Not Applicable

Amortization Basis - 10%
20 years
Amortization Factor - .117

Capital Costs

1. Take running total cost from option #5 column of strategy #5 at a flow rate of 10 mgd.

   Base Cost is $4,700,000

2. Determine multiplier to account for flow change using the 0.6 exponential rule. This is done by taking the ratio of the new flow rate 25 mgd to the old flow rate 10 mgd to the 0.6 exponential.

   Flow Change Multiplier is $(25/10)^{0.6} = 1.73$

The new base cost is then taken as the product of this multiplier and the base cost.

Flow Adjusted Cost is 1.73 x $4,700,000 = $8,130,000

3. Determine the price adjustment due to changes in the national cost structure by first calculating the National Cost Factor as the ratio of the prevailing index and the base index employed for this report. (175) for the STPCCI index and 169 for the ENR index.)

National Cost Factor is (180/175) = 1.03

This multiplied by the flow adjusted cost yields the Price Index Adjusted Cost.

Price Index Adjusted Cost is 1.03 x $8,130,000
= $8,370,000

4. Determine the local multiplier.

Local Multiplier = 1.1

5. Determine variations in price due to local considerations by taking the product of the local multiplier and the Price Index Adjusted Cost. This yields the Total Adjusted Cost.

Total Adjusted Cost is 1.1 x $8,370,000 = $9,210,000

6. Take the land requirement from the profile sheet by adding the requirements for each of the liquid treatments and option #5.

Base Land Requirement is 19 + 3 + 260 = 282 acres

7. Determine the Land Requirement Multiplier from the ratio of the desired flow rate to that flow rate on the profile sheet using the 0.6 exponential rule.

Land Requirement Multiplier is $(25/10)^{0.6}$ = 1.73

NOTE: This number should be the same as the previously calculated flow change multiplier in Item 2.

8. Determine the Adjusted Land Requirement by taking the product of the Base Land Requirement and the Land Requirement Multiplier.

Adjusted Land Requirement is 1.73 x 282 = 488 acres

9. Calculate the Adjusted Land Cost by taking the product of the Local Land Value and the Adjusted Land Requirement.

Adjusted Land Cost is 1500 x 488 = $730,000

10. The Total Capital Expenditures can now be calculated as the sum of the Total Adjusted Cost and the Adjusted Land Costs.

Total Capital Expenditures = $9,210,000 +
$730,000 = $9,940,000

Operating Costs

1. The Base Labor Requirement is taken from the profile sheet as the sum of the man-year requirements for the liquid treatment processes and the selected sludge option #5.

Base Labor Requirement is 3.2 + 7.9 + 13.9
= 25 man-years

2. The Labor Multiplier is calculated by taking the ratio of the desired flow rate and the base flow rate to the 0.58 power.

Labor Multiplier is $(25/10)^{0.58}$ = 1.70

3. The Adjusted Labor Requirement can now be determined as the product of the Base Labor Requirement and the Labor Multiplier

Adjusted Labor Requirement is 25 x 1.70
= 42.5 man-years

4. The Base Electrical Requirement is taken from the profile sheet as the sum of the energy requirements for the liquid treatment processes and the selected sludge option #5.

Base Electrical Requirement is 1270 + 3734 + 130
= 5134 KWhr/day

5. The Electrical Multiplier is calculated by taking the ratio of the desired flow rate and the base flow rate to the 0.55 power.

Electrical Multiplier is $(25/10)^{0.55}$ = 1.66

6. The Adjusted Electrical Requirement can now be determined as the product of the Base Electrical Requirement and the Electrical Multiplier.

Adjusted Electrical Requirement is 5134 x 1.66
= 8522 KWhr/day

7. The Base Chemical Requirement is taken from the profile sheet by including all entries from the liquid treatment process columns and the selected sludge option, #5.

Base Chemical Requirement is Chlorine 670 lbs/day
Conditioning Polymer 58 lbs/day

8. The Chemical Multiplier is calculated by taking the ratio of the desired flow rate and the base flow rate.

Chemical Multiplier is (25/10) = 2.5

9. The Adjusted Chemical Requirement can now be determined as the product of the Base Chemical Requirement and the Chemical Multiplier.

Adjusted Chemical Requirement is
Chlorine 670 x 2.5 = 1675 lbs/day
Conditioning Polymer 58 x 2.5 = 145 lbs/day

10. Fuel calculations do not apply in this example. If fuel were employed, the technique for cost adjustment would be the same as that for chemicals.

11. Fuel calculations do not apply in this example. If fuel were employed, the technique for cost adjustment would be the same as that for chemicals.

12. Fuel calculations do not apply in this example. If fuel were employed, the technique for cost adjustment would be the same as that for chemicals.

13. The Base Quantity of sludge requiring transportation is taken from the quotient of the sludges - total dry solids figure for sludges - percent dry solids figure for the selected sludge option #5. The figure should be converted to tons by dividing by 2000.

Base Quantity of Sludge = 14,000/(.06 x 2000)
= 117 tons/day

14. The Sludge Multiplier reflects the additional sludge generated by a change in plant size and is defined as the ratio of the desired flow rate and the base flow rate.

Sludge Multiplier is (25/10) = 2.5

15. The Adjusted Quantity of Sludge requiring transportation can now be calculated as the product of the Base Quantity of Sludge and the Sludge Multiplier.

Adjusted Quantity of Sludge if 117 x 2.5 = 293 wet tons/day

16. The Volume of Effluent requiring transportation is merely the new desired flow rate. This should be expressed in 1000 gal/day quantities since operating costs are presented in these units.

Volume of Effluent is 25,000 x 1000 gal/day = 25 MGD

17. The Daily Labor Cost can now be calculated by taking the product of the Adjusted Labor Requirement, the Local Cost of Labor, and the conversion factor of 8 man-hours per man-day.

Daily Labor Cost is 42.5 x 5.00 x 8 = $1,700/day

18. The Daily Electrical Cost can now be calculated by taking the product of the Adjusted Electrical Requirement and the Local Cost of Power.

Daily Electrical Cost is 8522 x 0.02 = $170/day

19. The Daily Chemical Cost is calculated as the sum of the daily chemical costs derived by taking the product of the Adjusted Chemical Requirement and the Prevailing Cost of Chemicals.

Chlorine = 1675 x 0.05 = $84/day
Conditioning Polymer = 145 x 2.0 = $290/day

Daily Chemical Cost is $374/day

20. The Daily Fuel Cost does not apply in this example but is calculated in the same manner as the Daily Chemical Cost.

21. The Daily Solids Transportation Cost is calculated from the product of the Adjusted Quantity of Solids, the Transport Distance for Sludges, and the Transport Cost for Sludge.

Daily Solids Transportation Cost is 293 x 60 x 0.05
= $879/day

22. The Total Daily Cost is now determined as the sum of the Daily Labor, Electrical, Chemical, Fuel, and Solids Transportation Costs.

Total Daily Cost is 1700 + 170 + 374 + 0 + 879
= $3,123/day

23. The Total Cost/1000 gal is now calculated by dividing the total daily cost by the volume of effluent in 1000 gal/day units.

Total Cost/1000 gal is 3123 ÷ 25,000 = $\underline{\$0.125/1000\ \text{gal}}$

24. The cost for effluent transportation is taken as the product of the volume of effluent, the transport distance for effluent, and transport cost for effluent. This figure does not apply to this example.

25. The Adjusted Operating Cost is the sum of the Total Cost/1000 gal and the cost for effluent transportation.

Adjusted Operating Cost is 0.125 + 0 = $\underline{\$0.125/1000\ \text{gal}}$

26. The Adjusted Amortization Cost is calculated by taking the product of the total capital expenditures and the amortization factor and dividing by 365 days/year and the volume of effluent in 1000 gal units.

Adjusted Amortization Cost is (9,940,000 x .117) ÷ (365 x 25,000) = $\underline{\$0.127/1000\ \text{gal}}$

27. The Total Adjusted Operating Cost is calculated by taking the sum of the Adjusted Operating Cost and the Adjusted Amortization Cost.

Total Adjusted Operating Cost is 0.125 + 0.127 = $\underline{\$0.252/1000\ \text{gal}}$

SAMPLE WORKSHEET

Assumptions

Plant Type -

Flow Rate -

Prevailing Construction Index - EPA -

ENR -

Local Multiplier -

Local Land Value - $ /acre

Local Cost of Labor - $ /hr (weighted average for operating labor and supervision)

Local Cost of Power - $ /kW-hr

Prevailing Cost of Chemicals

________________@ $_________/lb

________________@ $_________/lb

________________@ $_________/lb

________________@ $_________/lb

Transport Distance for Sludge miles round trip

Transport Cost for Sludge $/ton-mile

Transport Distance for Effluent miles

Transport Cost for Effluent $/1000 gal

Amortization Basis ________ %

________ Years

Factor ________

Capital Costs

Estimated Cost

1. Running Total Base Cost on Profile Sheet $___________for______flow

2. Flow Change Multiplier = _______________

Flow Adjusted Cost = $________________________

3. National Cost Factor = (/175) = _______________

Price Index Adjusted Cost = $________________________

4. Local Multiplier = __________

5. Total Adjusted Cost = $________________________

6. Base Land Requirement from Profile Sheet __________acres

7. Land Requirement Multiplier = (_____/_____)$^{.6}$ = ______

8. Adjusted Land Requirement = _________x_______ = ____acres

9. Adjusted Land Costs = _______ x _______ = $______________

10. Total Capital Expenditures = $______________

Operating Costs

1. Base Labor Requirement on Profile Sheet ______________man years

2. Labor Multiplier (_______/_______)$^{.58}$ =_______man years

3. Adjusted Labor Requirement = _________________man years

4. Base Electrical Requirement on Profile Sheet _________________kW-hr/day

5. Electrical Multiplier = (_____/_____)$^{.55}$ = ____________

6. Adjusted Electrical Requirement =

_______________x _________ = _________________kW-hr/day

7. Base Chemical Requirements on Profile Sheet ____________________lb/day

8. Chemical Multiplier = (_____/_____)$^{1.0}$= _________

9. Adjusted Chemical Requirement = _______ x _______

____________________lb/day

10. Base Fule Requirement on Profile Sheet ___________________Btu/day

11. Fuel Multiplier = (______/______)$^{1.0}$ = __________

12. Fuel Requirement = ________ x ________ =

___________________Btu/day

13. Base Quantity of Sludge requiring transportation _________________tons/day

14. Sludge Multiplier (_____/_____) = ______________

15. Adjusted Quantity of Sludge requiring transportation _________________tons/day

16. Volume of Effluent Requiring Transportation ____________ 1000 gal/day

17. Daily Labor Cost _____ x _____ x 8 =

$__________________ /day

18. Daily Electrical Cost _____ x _____ =

$__________________/day

19. Daily Chemical Cost ______ x _____ =

$__________________/day

20. Daily Fuel Cost _________ x _______ =

$__________________/day

21. Daily Solids Transportation Cost ______ x ______ =

$__________________/day

22. Total Daily Cost ________ + ________ + ________ +
________ + ________ = $__________________/day

23. Total Cost/1000 gal _________ ÷ _________ =
$_____________/1000 gal

24. Cost for Effluent Transportation _________ x ________
x _________ = $_____________/1000 gal

25. Adjusted Operating Cost _________ + _________ =
$_____________/1000 gal

26. Adjusted Amortization Cost @ 10% for 20 Years
(______x______) ÷ (365 x ______) =
$_____________/1000 gal

27. Total Adjusted Operating Cost
___________ + _________ = $_____________/1000 gal

LAND APPLICATION COST VARIATIONS

The cost of land disposal practices will vary greatly from facility to facility. For the most part, this variation is due to local differences in land values. Land values generally follow an established pattern in urban areas with land prices extremely high in the core city except perhaps for blighted areas or similar low-value enclaves. Values then decrease slowly as one moves outward. Recreational areas such as lakes and rivershores, suburban shopping centers, or other points of interest form similar higher value centers. The rate of decrease in value is related to the importance and drawing power of the attraction. A mapping of value regions would form a topographical map as conceptualized in Figure 28.

Hence, land value in general decreases with distance from the core city. Transportation costs, on the other hand, are proportional to the distance over which effluent or sludge must be moved, excepting those components of cost related to overhead, loading, and unloading. The costs for land applications of effluent sludges are high near the core city due to land value considerations and high at great distances due to transportation costs. Generally, some intermediate region represents the minimum cost zone. This relation is conceptualized in Figure 29.

Over a period of years, land may become exhausted in its capacity to retain heavy metals and phosphates. When this occurs, additional acreage must be sought. Thus, the band of minimum cost land moves outward from the city over a period of time. This outward movement may be accelerated both by growth in population and increases in urban land values.

While the actual range of land values that will be encountered at a specific facility vary with the location of that facility, transportation costs can be generalized. The relation of cost per ton of liquid digested sludge hauled versus distance is presented in Figures 30 to 32 for various sized plants. The cost curves vary with plant size in response to economies of scale in storage and loading facilities. Other cost items include operation and maintenance as well as the actual transportation costs themselves, e.g., fuel, salaries, power, and amortization. Data is presented in Figures 33 and 34 showing the relation between cost per ton and size of facility for short and long distances respectively. General assumptions made in the analysis are listed below:

• Per capita production of sewage solids	0.20 lbs/person/day
• Sludge concentration after thickening	5%
• Volatile matter content of raw sludge	75%

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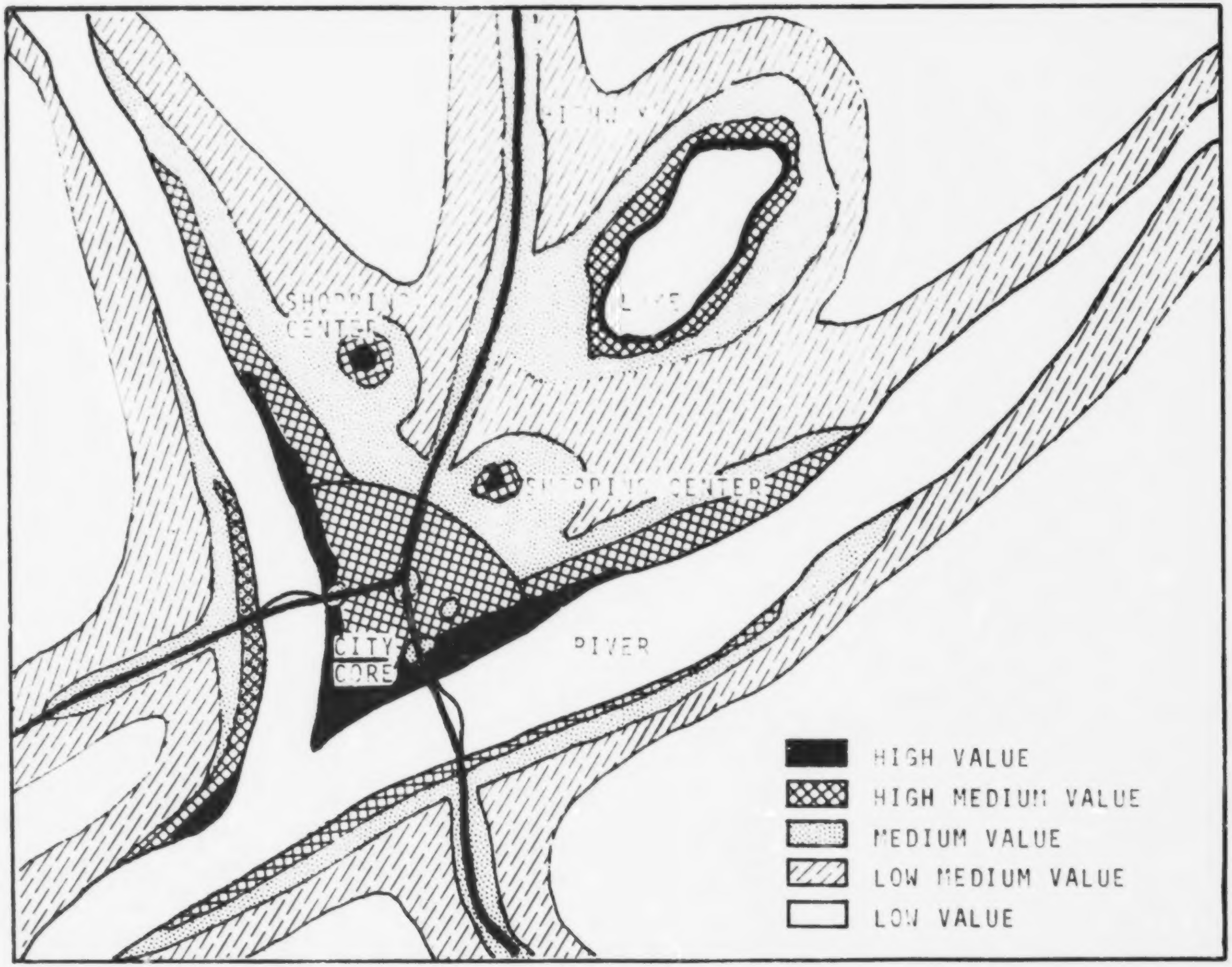
SHOPPING CENTER
LAKE
SHOPPING CENTER
CITY CORE
RIVER
HIGH VALUE
HIGH MEDIUM VALUE
MEDIUM VALUE
LOW MEDIUM VALUE
LOW VALUE

FIGURE 28. CONCEPTUALIZED PATTERN OF LAND VALUES FOR AN URBAN AREA

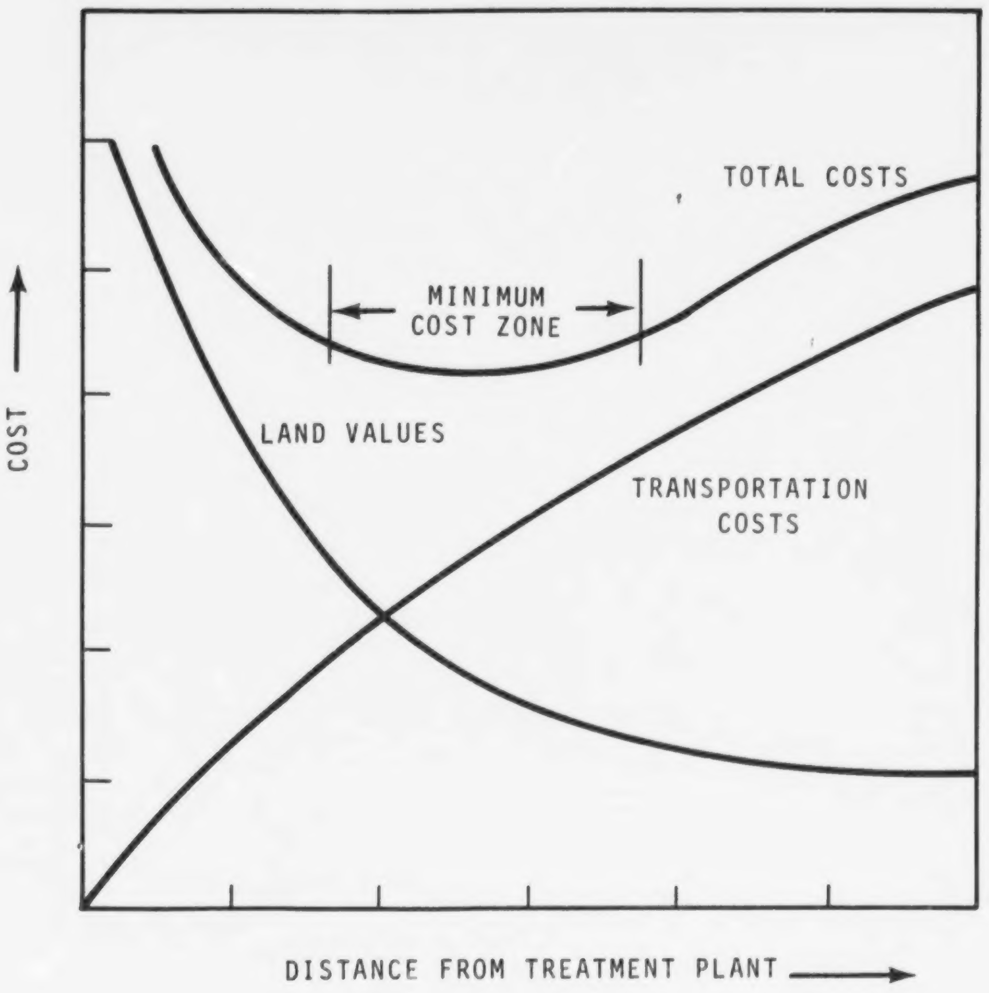

FIGURE 29. CONCEPTUALIZED RELATION OF TOTAL LAND APPLICATION COSTS TO DISTANCE FROM SOURCE

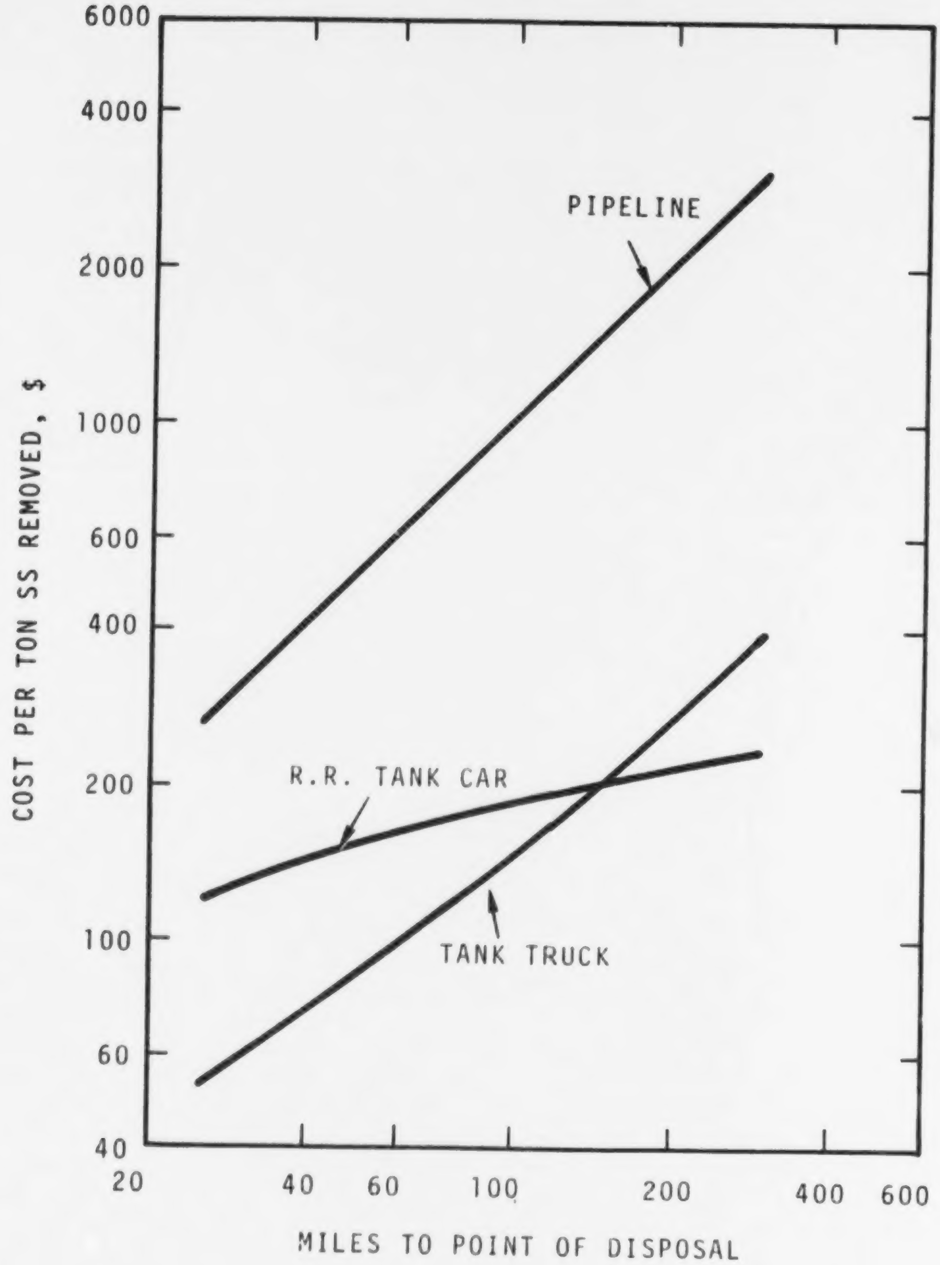

FIGURE 30. TRANSPORTATION COSTS FOR A FACILITY SERVING A POPULATION OF 10,000[72] (FLOW EQUIVALENT, 1 MGD)

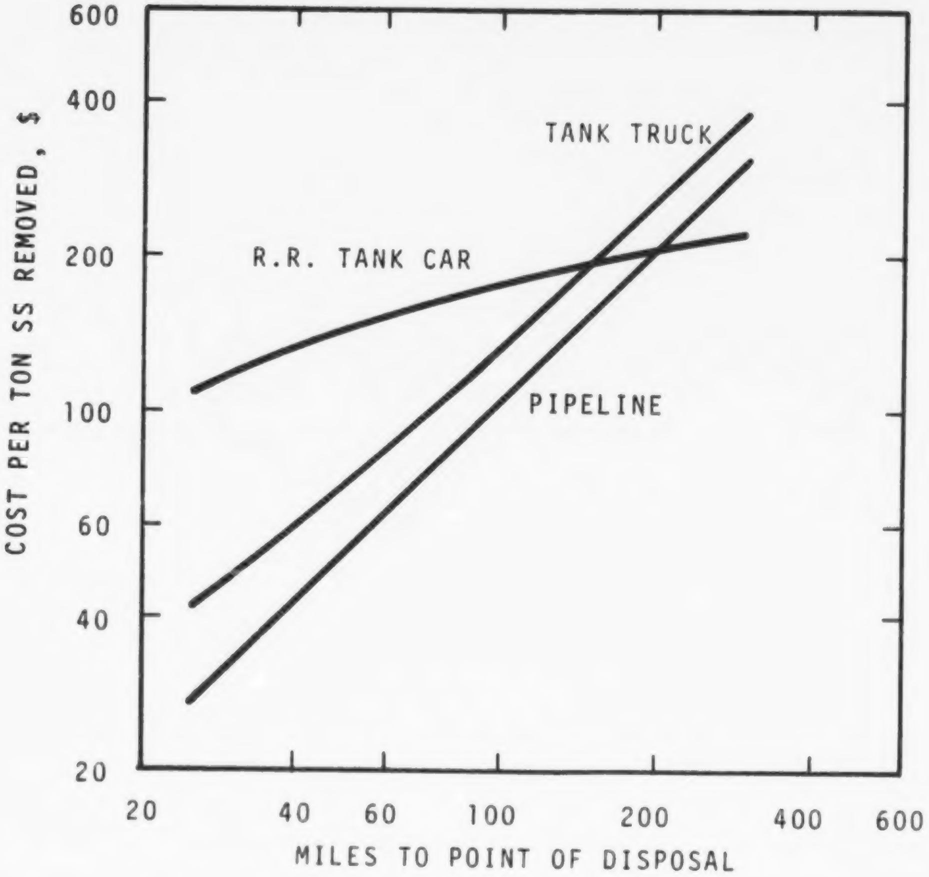

FIGURE 31. TRANSPORTATION COSTS FOR A FACILITY SERVING A POPULATION OF 100,000[72] (FLOW EQUIVALENT, 10 MGD)

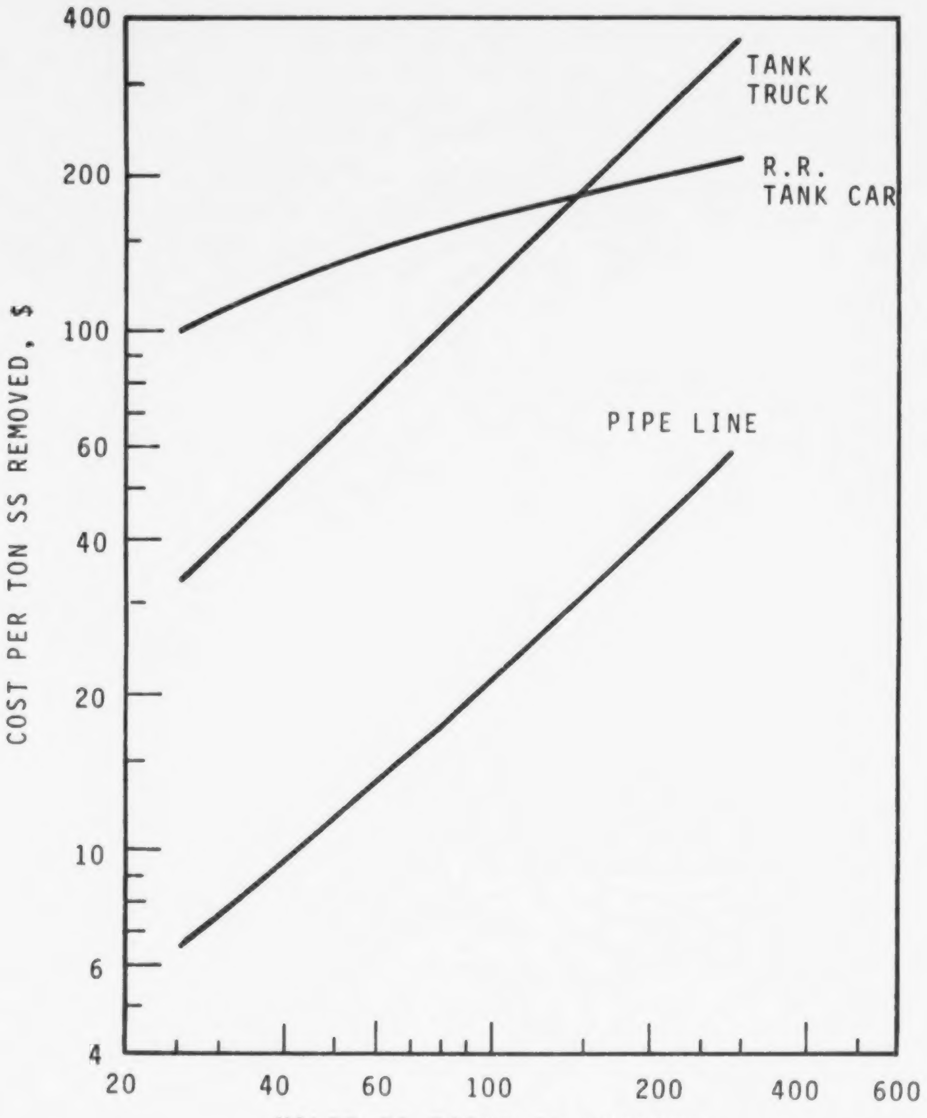

FIGURE 32. TRANSPORTATION COSTS FOR A FACILITY SERVING A POPULATION OF 1,000,000[72] (FLOW EQUIVALENT, 100 MGD)

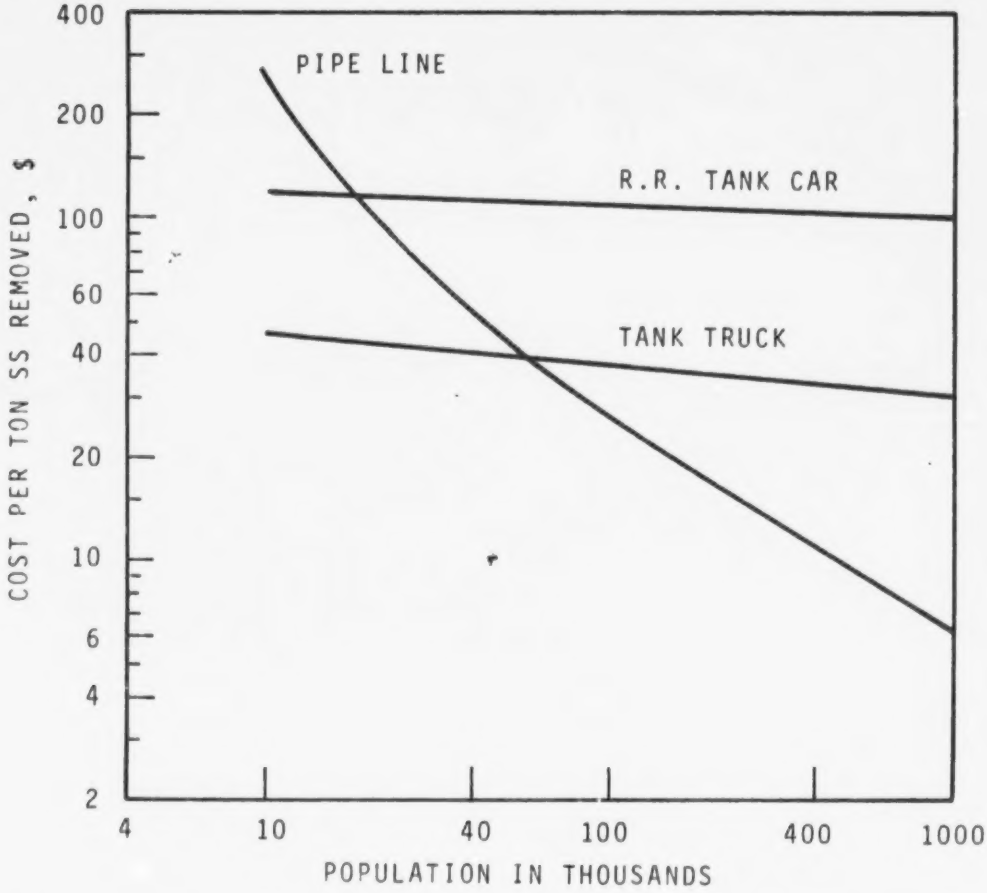

FIGURE 33. TRANSPORTATION COSTS FOR VARIOUS SIZED FACILITIES SHIPPING SLUDGE OVER A 25 MILE DISTANCE[72] (ASSUME 100 GALLONS/CAPITA/DAY FOR FLOW EQUIVALENTS)

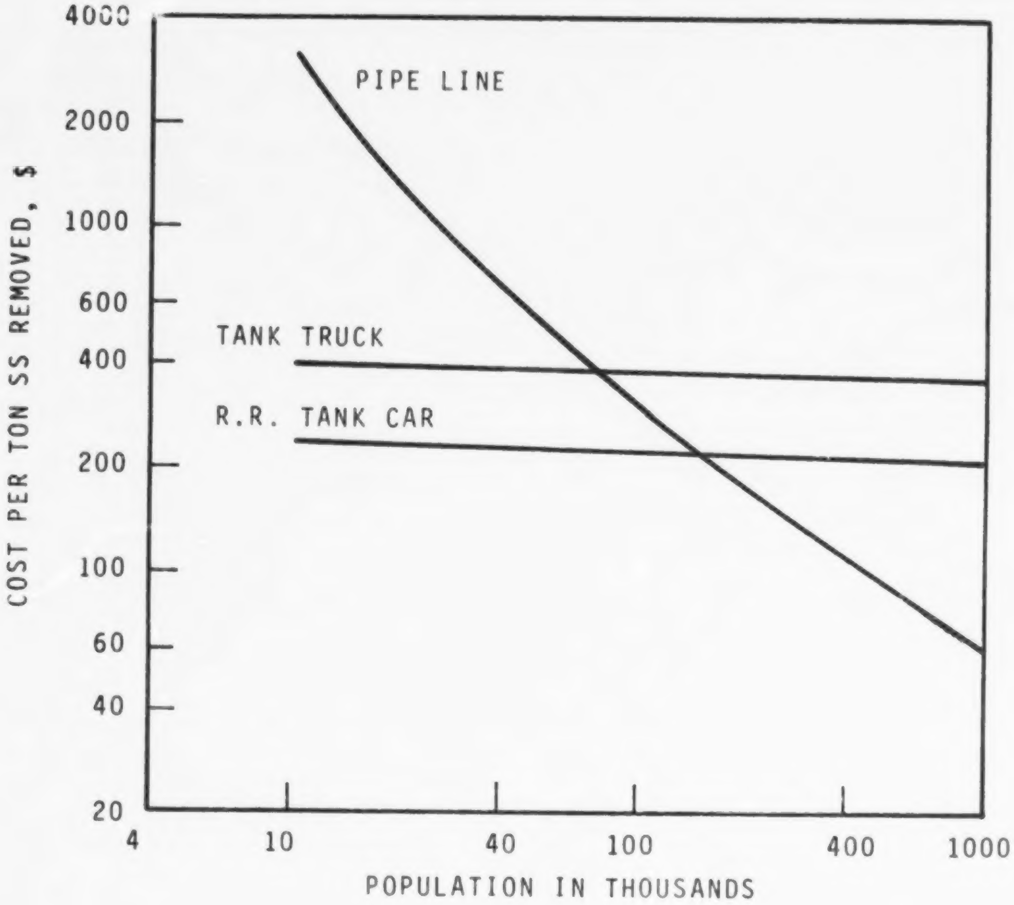

FIGURE 34. TRANSPORTATION COSTS FOR VARIOUS SIZED FACILITIES SHIPPING SLUDGE OVER A 300 MILE DISTANCE[72] (ASSUME 100 GALLONS/CAPITA/DAY FOR FLOW EQUIVALENTS)

- Reduction in volatile matter by digestion 50%
- Digested Sludge concentration 3.5%

Based on these assumptions, it is evident that truck transportation is economical for small plants (1 MGD or less) transporting over distances up to 150 miles. At this distance, rail shipment becomes competitive. For short distances (25 miles), pipelines are not economical until flow exceeds 6 MGD. For a 300 mile transport distance, pipelines become economical at a plant flow rate of 15 MGD. Higher sludge solids concentrations would make truck and rail more competitive.

For dewatered or dry solids transportation, trucking is the preferred alternative up to fairly long distances where rail becomes competitive. Barging is economical only for long hauls of large quantities.

For effluent water produced in excess of 10,000 gpd, pipelines are the only economical means of transportation. The relationship between costs for various modes of transportation over a spectrum of distances can be seen in Figure 35.

The preceding analysis assumes that land application of effluents or sludges requires purchase or leasing of land. This may not always be the case. In instances where residents of the agricultural community wish to utilize the effluent resources, no charges may be incurred. This is a relatively unstable arrangement, however, unless long-term commitments can be obtained. Typically, leases or land purchase will be the preferable mode of operation, thus insuring long-term stability and greater control over land use and loading rates.

If land is purchased, amortized purchase price is not necessarily a good measure of annual operating cost since the land can be resold. Indeed, land value will probably increase rather than decrease. A better measure of annual cost would be to amortize the difference in the present worth of the land and the present worth of its value after use is completed. This practice, however, was not employed in the present program. Obviously, under a lease arrangement, the annual charge is the appropriate operating cost.

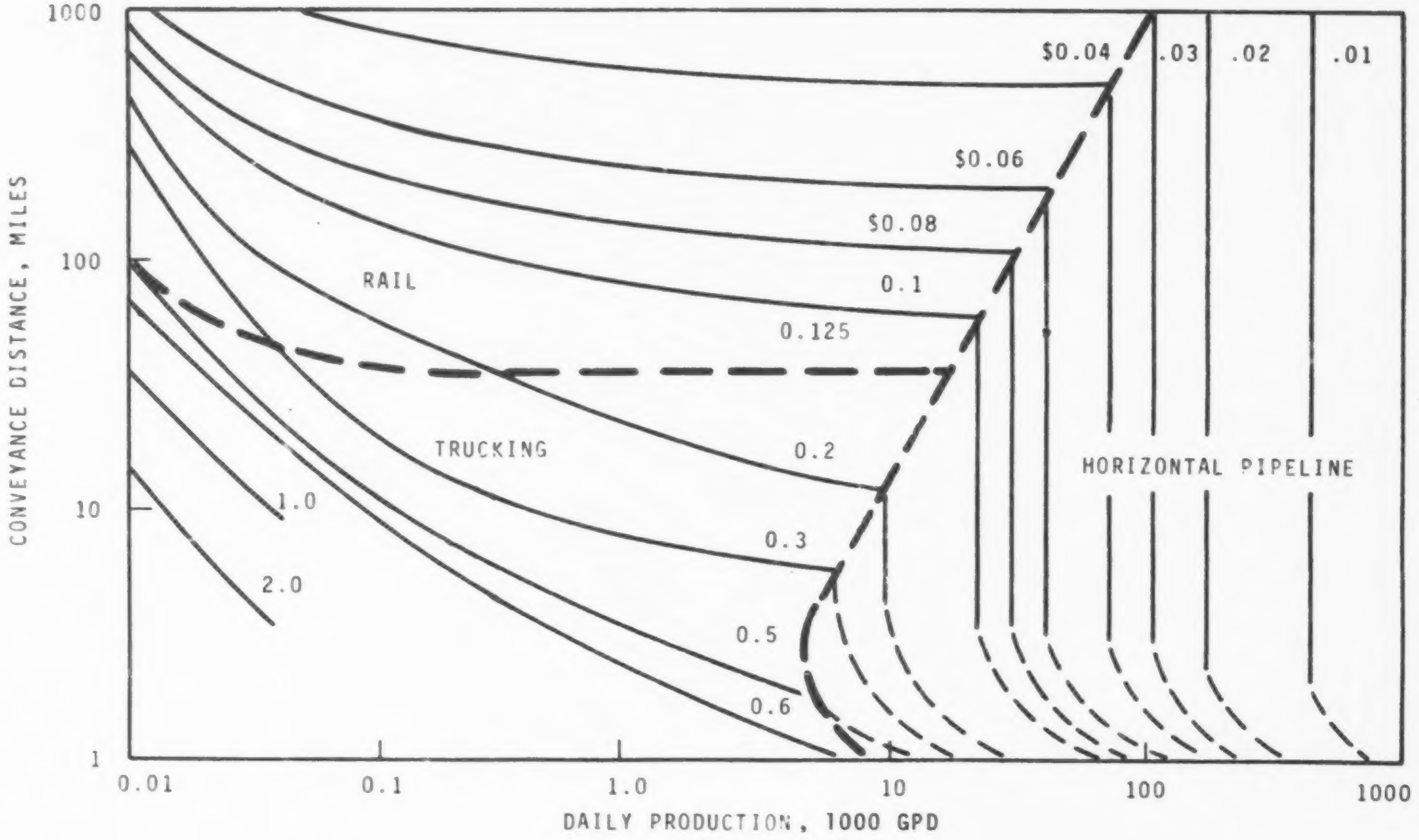

FIGURE 35. COST RELATIONSHIPS FOR CONVEYANCE OF EFFLUENT WATER BY PIPELINE, TRUCK, AND RAIL IN $/1000 GALLON/MILE[216]

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APPENDIX A

LIQUID TREATMENT PROCESSES

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APPENDIX A

LIQUID TREATMENT PROCESSES

GENERAL

The following sections of this appendix are designed to provide a description of each liquid treatment unit process employed in the eleven treatment strategies evaluated in this part. Each discussion is aimed at providing information on major parameters involved in design and/or installation of the process, the factors which affect performance of that process, and the general assumptions that were made in the development of the data presented in the profile sheets of this report.

The unit process design assumptions combined with specific design parameters presented in the liquid treatment strategy descriptions in the text of this report are intended to provide sufficient information on land and labor requirements and capital and operating costs to enable reconstruction of data where greater detail is desired.

PRIMARY TREATMENT

Process Description

Primary wastewater treatment is concerned with the removal of solids from wastewaters. This includes the removal of settleable, coarse, and suspended solids. Settleable solids include those solids which settle readily such as sand, coffee grounds, and rice, inclusively known as "grit". Coarse solids include branches, rags and other large floating debris. Suspended solids are those solid particles which require a quiescent period of gravity settling for removal. Settleable and coarse solids are generally removed by so-called preliminary treatment and suspended solids by primary sedimentation. Primary treatment includes both preliminary treatment and primary sedimentation. In addition, primary treatment normally involves flow measurement of influent wastewater.

The removal of coarse solids in preliminary treatment involves the use of screening and/or shredding devices. Screening devices include bar screens (bar racks) and traveling water screens. Shredding devices include comminutors, barminutors and pulverizing pump units. Screening devices are intended for entrapment of floating debris and subsequent removal. Shredding devices cut or grind up the coarse solids to allow for their passage to downstream treatment units for subsequent removal.

The removal of settleable solids, or grit, is achieved via grit removal devices of several different designs. Grit removal equipment is utilized to remove abrasive solids from wastewater, to provide protection of mechanical equipment, and to reduce deposits of grit in downstream treatment appurtenances. Grit removal equipment may be located before or after primary sedimentation.

Grit removal equipment located after primary sedimentation receives primary settled sewage for degritting, and includes centrifuges and hydraulic cyclones as solids removal devices. The reason for locating grit removal equipment after primary sedimentation is to reduce the size, and thus capital costs, of grit removal equipment. Size reduction is due to the volume reduction of sludge as compared to influent wastewater. Grit removal equipment located after primary sedimentation will allow the grit to pass through the primary clarifier and primary influent pumps (if pumps are used). However, it is thought by some that the grit will not cause excessive wear on this equipment, and that reduction in costs resulting from the use of smaller grit removal equipment will significantly offset increased maintenance costs on mechanical equipment caused by the grit.

Locating grit removal equipment before primary sedimentation protects downstream pumping equipment and the sludge scraper mechanism in the primary clarifier from abrasive wear. Various designs of grit chambers are used for this type solids removal. For the purposes of this report, a grit chamber located before primary sedimentation was the alternative considered.

Primary sedimentation involves the separation and removal of suspended particles that are heavier than water and lighter than water. Suspended particles heavier than water are removed via quiescent gravitational settling. Those solids lighter than water float to the surface as a scum layer and are skimmed from the surface. The removal of settleable and floating material reduces the suspended solids content by 50 to 65 percent with an associated reduction in BOD of 25 to 40 percent.[31]

Primary sedimentation may be used to provide the principal degree of treatment or may be used as a preliminary step in a biological secondary treatment sequence that will provide greater degrees of treatment. Primary sedimentation which precedes secondary biological treatment is normally designed to provide shorter detention times and higher surface loading rates than when designed for primary treatment as the only method of treatment. Normally, primary sedimentation tanks are designed to provide 90 to 150 minutes of detention based on the average daily rate of flow of influent wastewater. Primary sedimentation tanks preceding secondary biological treatment normally are designed to provide 30 to 60 minutes of detention.[31]

Currently, sedimentation tanks are designed on the basis of surface loading rates. The surface loading rate, or surface overflow rate, is based on the average daily flow and expressed as gallons per day per square foot (gpd/sq ft) of tank surface area. The selection of a suitable loading rate must meet the approval of state regulatory agencies, most of which have adopted standards that must be followed. Many state standards are based on the Ten State Standards [14] which require that surface loading rates for primary sedimentation not followed by secondary treatment "...shall not exceed 600 gpd/sq ft for plants of 1 MGD size or less". Larger plants may use higher surface loading rates, but for the purposes of this report 600 gpd/sq ft is considered optimum.

Based on the design flow, the surface area of the tank is determined, reflecting the 600 gpd/sq ft criteria. After the surface area of the sedimentation tank is established, the detention time is determined by water depth as shown in Table A-1.

TABLE A-1

DETENTION TIMES FOR VARIOUS SURFACE LOADING RATES AND TANK DEPTHS[31]

	Detention time, hr			
Surface Loading rate, gpd/sq ft	7 ft depth	8 ft depth	10 ft depth	12 ft depth
400	3.2	3.6	4.5	5.4
600	2.1	2.4	3.0	3.6
800	1.6	1.8	2.3	2.7
1,000	1.3	1.4	1.8	2.2

It should be emphasized that surface overflow rates must be set low enough to ensure satisfactory performance at peak hydraulic flow rates, which may vary from 3 times the average flow in small plants to 1.5 the average flow in large plants.[31] Figure A-1 shows the effect of overflow rate on suspended solids removal and Figure A-2 shows the effect of overflow rate on BOD removals.

The effect of the surface loading rate and detention time on suspended solids removal varies widely depending on the character of the wastewater, proportion of settleable solids, concentrations of solids, and other factors.

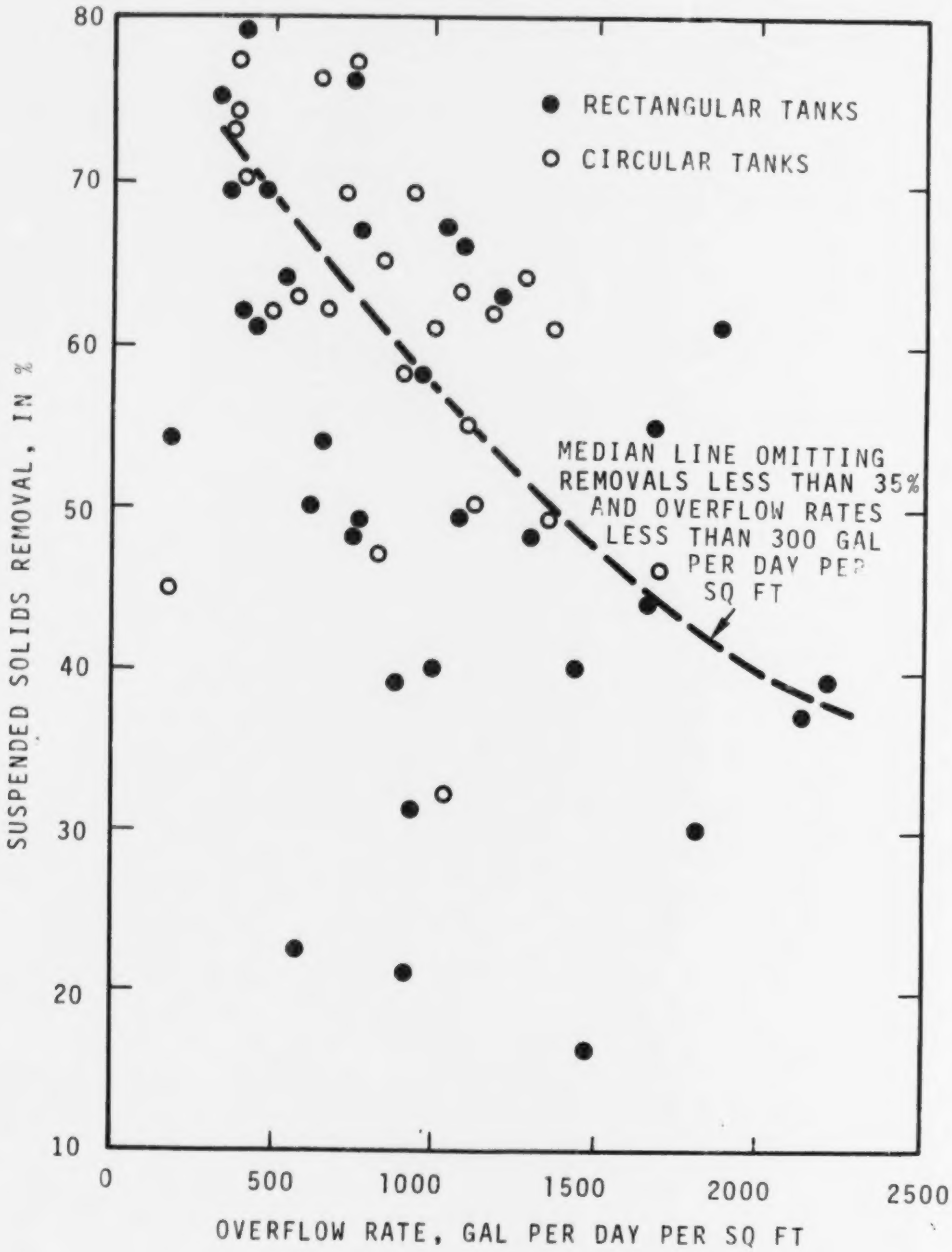


FIGURE A-1. PERFORMANCE OF SEDIMENTATION TANKS FOR SUSPENDED SOLIDS REMOVAL[19]

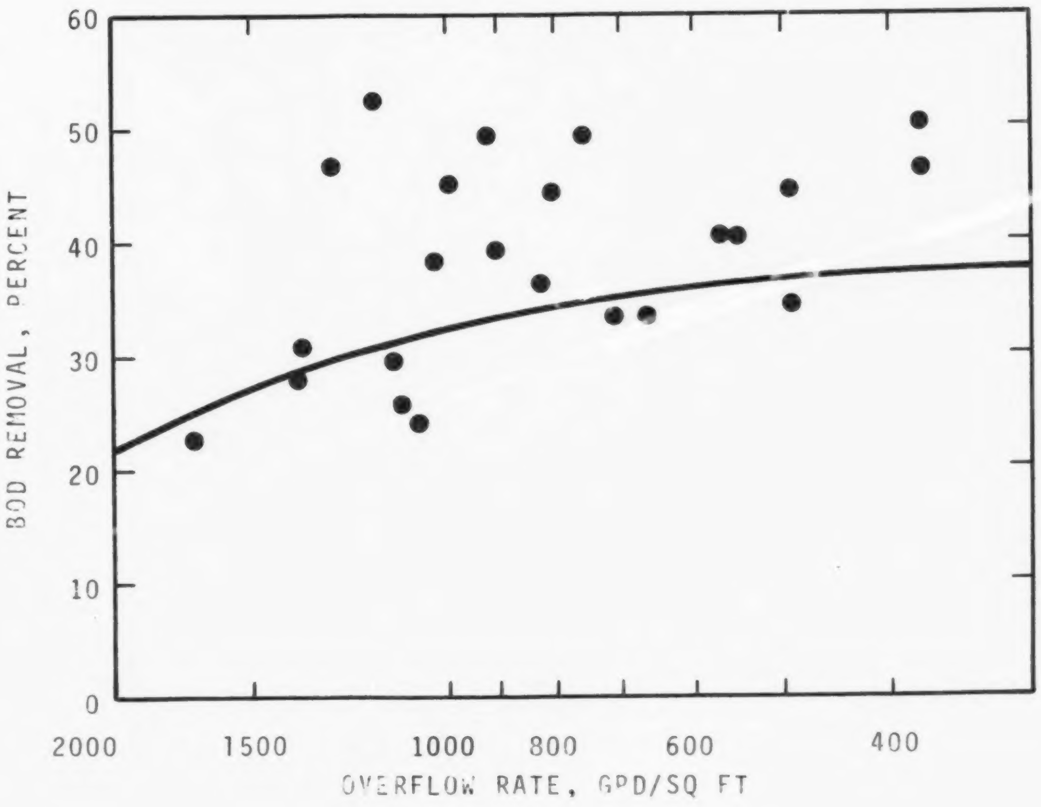


FIGURE A-2. BOD REMOVAL IN PLAIN SEDIMENTATION OF RAW WASTEWATER[32]

The maximum volume of solids will be removed by sedimentation when the flow through the settling tank is uniform, that is, when no extraneous currents are present that will interfere with particle settling velocities. Density currents may also reduce settling efficiency. Such currents are caused by influx of materials of lesser or greater specific gravities, as by the recycle of digester supernatant or by large variations in influent temperatures. Poorly designed inlets may induce interfering currents, and improper outlets may allow a loss of solids out of the tank. Wind may also cause rather high velocity currents on larger size clarifiers.

A large number of primary sedimentation tanks utilize lift stations for pumping wastewater into the tanks for treatment, and as such are dependent on a realiable source of power. In such cases emergency power supplies are required to assure continuous operation.

Design Assumptions

For the design and cost purposes of this report the design flow was based on the average daily flow and surface loading rate of primary sedimentation tanks was assumed at 600 gpd/sq ft. Solids loadings of 20-25 lbs/sq ft/day were assumed. Preliminary treatment, including screening and grit removal, precedes primary sedimentation.

Primary sludge solids production for the type and quality of wastewaters considered will provide approximately 900-1100 pounds per million gallons of wastewater treated.

WASTE STABILIZATION PONDS

Domestic wastewaters may be effectively stabilized by the natural biological processes of relatively shallow ponds. Stabilization is carried out by the photosynthetic processes of algae and/or the oxidative processes of bacteria. Waste stabilization ponds (or lagoons, as they are sometimes called) have become very popular with small communities because their low construction and operating costs offer a significant financial advantage over other recognized treatment methods.

Waste stabilization ponds are generally classified according to the nature of the biological activity and environment within the pond. Thus stabilization ponds are classified as aerobic, aerobic-anaerobic (or facultative), and anaerobic. A waste stabilization pond system may include a single pond or a number of ponds in series or parallel. Also the differently classified ponds may be utilized in series, i.e., aerobic followed by an anaerobic, or vice versa. This is usually done to effect greater treatment efficiencies than can be achieved via a single pond type.

Aerobic ponds are generally separated into two categories based on whether natural or artificial methods of supplying oxygen to the bacteria in the pond are utilized. Lagoons which receive their oxygen supply by natural surface aeration and by algal photosynthesis are generally termed "oxidation ponds." Mechanical aeration units can be used to artificially supply oxygen to the bacteria and the process is essentially the same as the activated sludge process, without recycle of microorganisms. Mechanically aerated ponds are generally termed "aerated lagoons."

Oxidation ponds utilize algae and bacteria in a symbiotic relationship to stabilize waste organics. This is depicted in Figure A-3. The oxygen released by the algae through the process of photosynthesis is utilized by bacteria in the aerobic degradation of organic matter. The nutrients and carbon dioxide released via respiration are, in turn, used by the algae. During the daylight hours of increased algal photosynthetic activity, it is possible for oxygen concentrations to reach supersaturation levels. Generally solids will settle in an oxidation pond due to the lack of mixing. These settled solids accumulate, forming an anaerobic sludge layer on the bottom, and the pond becomes an aerobic-anaerobic (facultative) pond. Oxidation ponds generally are relatively shallow being 3 to 5 feet in depth.[194]

Aerated lagoons are an outgrowth of the development of the conpletely mixed activated sludge process in that surface mechanical aerators were applied to overloaded oxidation ponds. Aerated lagoons are generally constructed at depths of 8 to 15 feet.[55,194] Generally, no consideration is given to algae for supplying dissolved oxygen because the pond surface is turbulent inhibiting the growth of algae.

Aerobic-anaerobic, or facultative, ponds were historically known as stabilization ponds. The symbiotic algae-bacteria relationship is utilized to its fullest in these ponds. The ponds are generally 3 to 8 feet in depth and solids settle to the bottom to eventually decompose. This decomposition is anaerobic and results in the interchange of anaerobic decomposition byproducts and aerobic oxidation byproducts between the lower and upper portions of the pond.

Anaerobic ponds were the inevitable result of the widespread use of "stabilization" ponds (facultative) where the organic loading rates became excessive causing anaerobic conditions throughout the pond. The symbiotic stabilization relationship failed, but was substituted for by an anaerobic stabilization

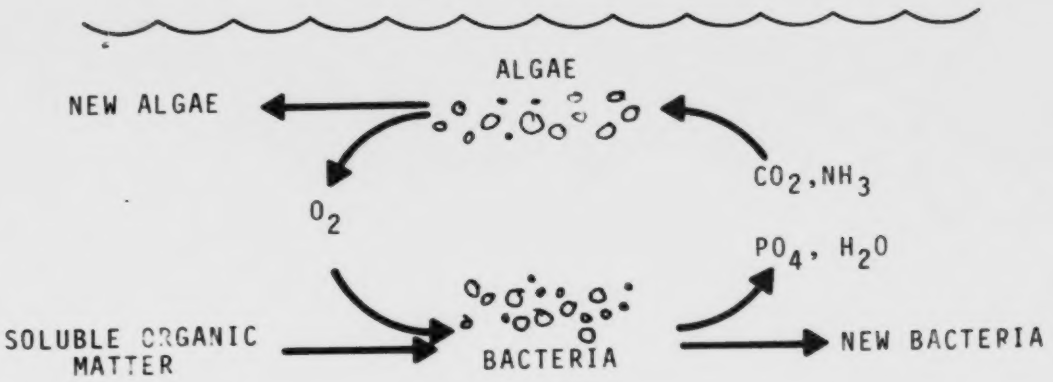

ALGAE
NEW ALGAE
CO_2, NH_3
O_2
PO_4, H_2O
SOLUBLE ORGANIC MATTER
BACTERIA
NEW BACTERIA

FIGURE A-3. SYMBIOTIC RELATIONSHIP BETWEEN ALGAE AND BACTERIA process where waste organics are stabilized by anaerobic methane forming bacteria similar to that which occurs in anaerobic digesters.

Stabilization ponds (aerobic, facultative and anaerobic ponds) have been found to be an effective and relatively inexpensive means of treating domestic wastes. Economic considerations and space requirements tend to make these methods of treatment most attractive to smaller urban areas. Table A-2 presents design criteria for stabilization ponds as will be discussed below.

Oxidation Ponds

Encouragement of the process of aerobic oxidation of wastes requires that design parameters be considered which promote a viable bacterial population, including dissolved oxygen, temperature, pH, nutrient source, and time.

The physical size of the pond establishes the majority of the above factors; temperature is a climatic parameter which cannot be controlled to any great extent. A discussion of the remaining criteria follows.

Loading criteria (lb BOD/acre/day) have been based on the ability of algae, through photosynthesis, to supply sufficient oxygen to bacteria for oxidation of waste organics. Oxidation ponds are constructed with large surface areas for maximum exposure to sunlight which is important for the growth of algae. Studies have indicated that photosynthetic efficiencies of only ten percent were possible in sewage oxidation ponds.[197]

Ice cover has been reported to decrease the light penetration to 0.5 to 15 percent of that reaching the surface. In the summer, approximately 99 percent of the light is absorbed in the top 24 inches of the ponds. Diurnal variations in photosynthetic supply of oxygen result in large concentration ranges of dissolved oxygen (high levels during the day and low at night).

To achieve best results with aerobic ponds, their contents must be mixed periodically with pumps or some type of aeration device. The efficiency of BOD conversion in aerobic ponds may be high. It should be noted that this BOD has been taken up in algae cells. The pond effluent may contain a large quantity of algae which will ultimately die, causing an oxygen demand. Therefore, to actually remove BOD requires removing the algae from the pond effluent.

Several techniques for separation have been attempted including centrifugation and chemical precipitation.[194] Perhaps the most economical and practical method to date is to operate several ponds in series with outlet structures designed to draw the final effluent from below the pond surface.

TABLE A-2

DESIGN PARAMETERS FOR STABILIZATION PONDS[31]

	Type of Pond				
Parameter	Oxidation Pond	Facultative	Mechanically Aerated Facultative	Anaerobic	Mechanically Aerated Lagoons
Detention time, days*	10-40	7-30	7-20	20-50	3-10
Depth, ft	3-4	3-6	3-8	8-15	6-20
pH	6.5-10.5	6.5-9.0	6.5-8.5	6.8-7.2	6.5-8.0
Temperature range, °C	0-40	0-50	0-50	6-50	0-40
Optimum temperature, °C	20	20	20	30	20
BOD_5 loading, lb/acre/day	60-120	15-50	30-100	200-4000	
BOD_5 conversion, percent	80-95	70-95	80-95	50-70	80-95
Principal conversion products	Algae, CO_2, bacterial cell tissue	Algae, CO_2, CH_4, bacterial cell tissue	CO_2, CH_4, bacterial cell tissue	CO_2, CH_4, bacterial cell tissue	CO_2, bacterial cell tissue
Algal concentration, mg/liter	80-200	40-160	10-40		

---

*Depends on climatic conditions

It is generally considered that in a period of 20 days at 20°C, bacteria are able to more or less completely stabilize the organic matter. However, if ice is covering the pond surface preventing sufficient oxygen development from the algae in winter months, artificial aeration must be utilized to produce a high quality pond effluent.

Aerated Lagoons

As mentioned previously, aerated lagoons are deeper versions of the oxidation pond where the contents of the pond are vigorously mixed with some type of aeration device. Little consideration is given to the contribution of algae for the supply of oxygen.

Aerated lagoons depend on aeration devices for supplying oxygen required to stabilize the organic matter. Aeration devices must also provide sufficient mixing to disperse oxygen and maintain solids in suspension. Mechanical aeration devices have been shown to supply considerably more oxygen per unit horsepower than air diffusion devices. However, in the extreme cold temperatures of the northern latitudes, mechanical aerators become inoperable during winter months. Subsurface air diffusion devices have proven quite effective in these instances.

Power level requirements of 0.02 to 0.03 hp/1000 gallons are required to maintain solids in suspension and approximately 0.01 hp/1000 gallons to disperse oxygen uniformly throughout the basin.[198] Generally the power input levels are around 100 hp/million gallons for aerated lagoons.[199] Studies have indicated the potential feasibility of obtaining 90 percent BOD reduction at 0.5°C temperatures in aerated lagoons operating with detention times of 10 to 15 days. Air diffusion devices are normally utilized for cold climate applications.

Facultative Lagoons

The aerobic-anaerobic or facultative lagoon is designed to take maximum advantage of the symbiotic relationship between algae and bacteria, and is characterized by two distinct zones; an aerobic zone and an anaerobic zone. Hydraulic and organic loadings are such that the dissolved oxygen in the lower sections of the lagoon is near zero and an aerobic layer is maintained above. A cross section of a typical facultative lagoon is shown in Figure A-4.

Actually, most so-called aerated lagoons constructed today are facultative lagoons. The facultative lagoon is designed with only sufficient power input to insure uniform dissolved oxygen in the upper layer of the lagoon. The aeration equipment is designed for minimum energy input, only that theoretically

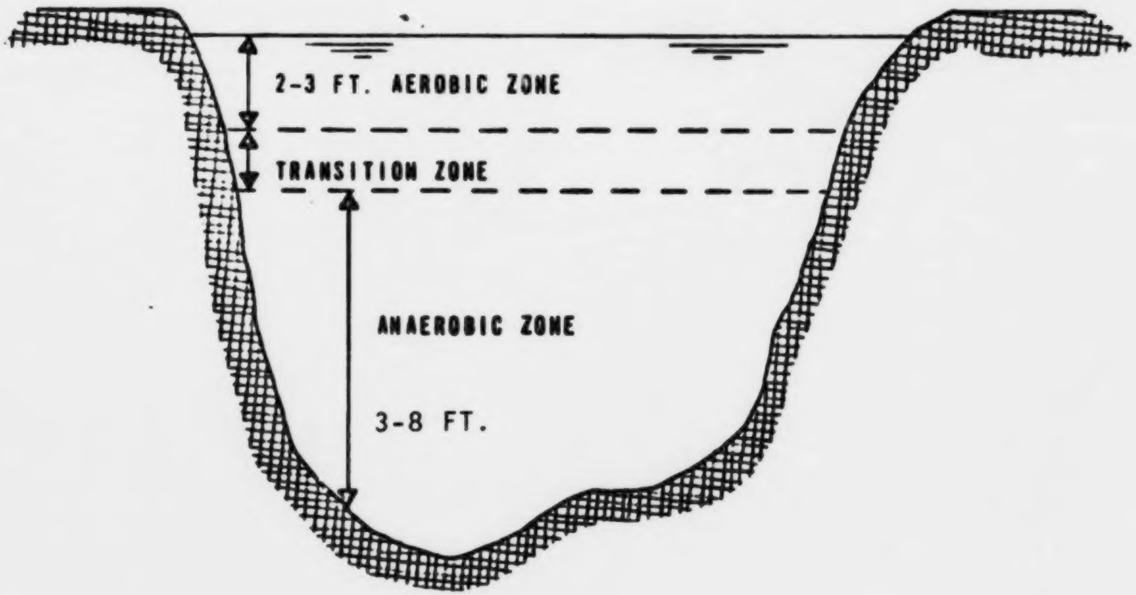

2-3 FT. AEROBIC ZONE
TRANSITION ZONE
ANAEROBIC ZONE
3-8 FT.

FIGURE A-4. TYPICAL CROSS-SECTION OF A FACULTATIVE LAGOON required to provide for oxygen supply. Therefore, the bulk of the solids are not kept in suspension but settle to the bottom for anaerobic decomposition. Sedimentation may be provided to obtain a clear effluent. Oxygen requirements for facultative lagoons are determined at 1.5 pounds of oxygen per pound of BOD applied.[194] Power input to a facultative lagoon is approximately 15 to 20 hp/million gallons of basin volume.[199]

Facultative lagoons are used almost exclusively rather than aerated lagoons because an equal quality effluent is produced with lower power inputs.[119]

Anaerobic Lagoons

Anaerobic ponds are designed to maintain environmental conditions which are favorable for the development and growth of methane bacteria. The primary factors affecting the growth of methane bacteria are temperature, pH, detention time and organic loading. Methane bacteria grow relatively slowly compared to facultative organisms normally employed in aerobic processes. Free dissolved oxygen in the environment is inhibitory to these organisms. The minimal temperature for active growth of methane bacteria is approximately 20°C. The methane bacteria are sensitive outside a rather narrow pH range of 6.6 to 7.2.

Anaerobic ponds are loaded to such an extent that anaerobic conditions exist throughout the lagoon. The anaerobic digestion process in the lagoon is a two-stage process of organic acid formation followed by methane fermentation. Organic loadings of 500 to 2,000 lb BOD/acre/day are usually employed, resulting in removal efficiencies of approximately 70 percent.

Extensive studies of anaerobic lagoons in California indicate that the establishment of methane fermentation within anaerobic lagoons will minimize nuisance odor problems generally associated with these types of lagoons.[200] BOD loading necessary to create environmental conditions favoring anaerobic reactions may be as little as 100 lbs BOD/acre/day in the winter or as much as 400 lbs BOD/acre/day in the summer.[200]

Anaerobic lagoons should be designed to provide a small surface area-to-volume ratio for retention of maximum heat content. Large surface areas present an opportunity for increased heat exchange potential with the air.

A major advantage of anaerobic lagoons is the minimal attention required for maintenance and laboratory control. In most cases the lagoons are constructed and placed into operation on strictly an empirical basis. Once placed into operation they are generally unattended.

Anaerobic lagoons have not been considered adequate as a complete wastewater treatment process and are generally followed by aerobic type ponds to achieve higher quality effluents.

Design Assumptions

As previously indicated, waste stabilization ponds appear to provide the least expensive (both capital and operating) alternative for sewage treatment plants of less than 1 MGD. Mechanically aerated facultative ponds have been selected as the type of waste stabilization pond most likely to be installed in a small community. Facultative ponds are characterized by minimum operational and maintenance requirements, capital costs, odor nuisance, and relatively high BOD removals. Furthermore, it was assumed that no sludge production would occur from the system. As the pond fills with decomposed solids, it would be eventually covered with soil and a new site excavated.

The final effluent from the system will be drawn below the pond surface to minimize the release of algae. The effluent will be either released to surface waters or applied to the land by spray irrigation. The design loadings and parameters indicated previously in Table A-2 for mechanically aerated facultative ponds were assumed to apply. Cost data and size requirements appearing on the profile sheets reflect a pond located in a temperate climate. Extremely cold climates will cause adjustments of the data. The electrical power requirements were assumed to vary between 15 and 20 hp/million gallons of basin volume.[199] An average detention time of fifteen days was also assumed.

ACTIVATED SLUDGE PROCESS

Process Description

The need for increasing degrees of wastewater purification has created a continually growing interest in the activated sludge process. In recent years it has become the most popular biological wastewater treatment process. There is every reason to believe that it will find even greater use in the future, especially in combination with so-called "advanced physical-chemical" treatment methods, which will be discussed in a later subject phase.

The activated sludge process which was developed in England about 60 years ago involves the production of a suspended mass of microorganisms in a reactor to biologically degrade soluble organic compounds in wastewater to carbon dioxide, water, microorganisms and energy. The flocculant biological solids (sludge) are continuously circulated and mixed with incoming organic wastes in the presence of molecular oxygen. Ardern and Lockett,[163] discoverers of the activated sludge process, in reporting the results of their studies referred to the flocculant biological solids (sludge) as being "activated." In their aeration studies, they saved the flocculant biological solids (sludge) for use in subsequent experiments and were amazed at the increased effectiveness each time the experiment was repeated, thus the term "activated sludge." As a basic biological treatment system, it remained nearly unchanged during the first 30 years of its existence. Significantly, nearly all modifications of the system in the first 40 years of its use were the result of efforts of treatment plant operators, not consulting engineers or researchers. These early attempts at modification tended to treat the process as a "physical" system and thus often met with failure. Much of this difficulty was due to the lack of understanding that the process was biological-biochemical in nature. Only in more recent times have biological-biochemical considerations played a part in the design and/or operation of activated sludge systems.

In operation of the activated sludge process, wastewater containing soluble organic compounds is fed to the aerobic reactor (aeration tank) which furnishes 1) air required by microorganisms to biochemically oxidize the waste organics, and 2) mixing to insure intimate contact of microorganisms with the organic waste. The aerobic reactor contents are referred to as mixed liquor suspended solids (MLSS). In the vigorously mixed aerobic reactor, the organic wastes are metabolized to provide energy and growth factors for the production of more microorganisms with the release of carbon dioxide and water as metabolic end products. The organic waste compounds are thus degraded to innocuous end products and microorganisms. The mixed liquor suspended solids flow from the aeration tank to a sedimentation tank which provides quiescent settling to allow separation of the biological solids from the treated wastewater. The treated and clarified water is collected and discharged as process effluent. Most of the settled biological solids are recycled as return activated sludge (RAS) back to the aerobic reactor to provide an activated mass of microorganisms for continuous treatment of incoming wastewater. Some of the settled biological solids are wasted to maintain a proper balance in the population of microorganisms in the mixed liquor suspended solids of the aerobic reactor. Recycling and wasting of biological solids (microorganisms) from the reactor insures a proper ratio of incoming waste to the population of microorganisms (food to microorganisms, or F/M ratio), which is critical to efficient biodegradation of soluble organic waste compounds.

The term BOD (biochemical oxygen demand) is used to measure the strength of organics in wastewater and, as such, is a measure of the substrate level or food value of wastewater. The F/M ratio is the process loading factor and is expressed as pounds of BOD applied per day per pound of MLVSS (lb BOD/Day/lb MLVSS) contained in the treatment system. This process loading factor is being used in current wastewater treatment practice.[19] However, there is also another parameter that is often used to design aeration systems. The concept of BOD loading in terms of MLVSS is extremely important, but it should be used in conjunction with knowledge of air requirements and the ability of facilities to handle the system solids. For this reason it is common practice to also base design considerations on volumetric loadings, i.e., pounds of BOD per 1000 cubic feet of aeration tank. Used together, these two parameters act to "cross check" loading factors to ensure that the activated sludge system will operate effectively.

The activated sludge process is very flexible and can be utilized for the treatment of almost any type of biodegradable waste. The original process configuration is called the conventional activated sludge process, and has been modified in numerous ways. Characteristics, typical treatment efficiencies, and design criteria for these processes are shown in Table A-3.

For this study, the completely mixed activated sludge process was assumed as the method of treatment in cases where activated sludge treatment was required. Figure A-5 is a process flow schematic of the completely mixed process.

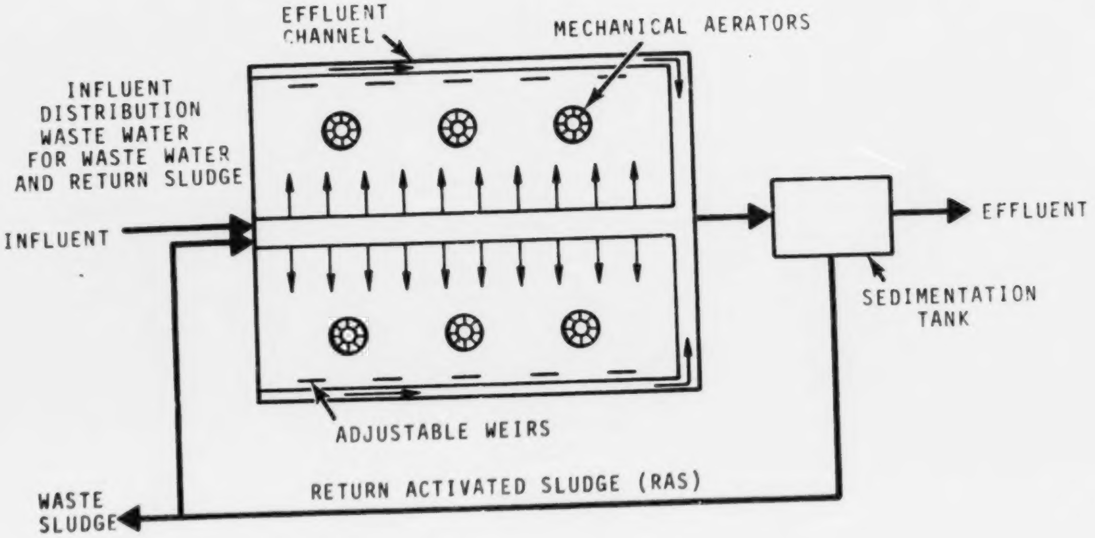
Perhaps the most significant contribution to activated sludge technology during the past twenty years has been the recent application of biochemistry to the activated sludge process. Awareness of biochemical relationships that govern the biological degradation of waste organics in the activated sludge process has enabled the development of the complete mix flow pattern and process.

In the complete mix system, influent wastewater is uniformly mixed throughout the entire aeration basin as rapidly as possible. The mixing tends to produce a uniform organic load through the entire contents of the aeration basin. Since the influent wastes are mixed throughout the aeration basin, the entire basin volume acts to buffer hydraulic surges and organic shock loads. For example, it has been shown that 100 mg/l of phenol is toxic to the conventional activated sludge process, whereas 2000 to 3000 mg/l phenol was not toxic in the complete mix system.[166] This enables the establishment of equilibrium (or nearly so) conditions for stable operation.

TABLE A-3

OPERATIONAL CHARACTERISTICS AND DESIGN PARAMETERS OF ACTIVATED SLUDGE PROCESSES[20,31,164,165]

	Conventional	High Rate or Modified	"Contact Stabilization"	"Extended Aeration"	"Complete" Mixing	Step Aerator	High Purity Oxygen Systems
Primary Sedimentation	Usually Provided	Optional	Optional	Generally None	Optional	Usually Provided	Optional
Flow Model	Plug Flow	Complete Mix	Plug Flow	Complete Mix	Complete Mix	Plug Flow	Complete Mix Reactors in Series
Aeration System	Diffused Air	Mechanical Aerators	Diffused Air Mechanical Aerators	Mechanical Aerators	Mechanical Aerators	Diffused Air	Mechanical Aerators
Aeration Period	5-10 hours	2-3-1/2 hours	20-40 mins. (mixing-aeration)	24 hours	2 hours	3-6 hours	1-3 hours
Secondary Sedimentation	yes	yes	yes	yes	yes	yes	yes
Return Sludge Flow	25-50%	10%	30-50%	up to 100%	up to 100%	25-50%	up to 100%
BOD Loading (lbs/day per lb MLVSS)	.25-.50	.20-.40	.15-.35	about .15	about .60	.25-.50	about .60
Sludge Age	3-6 days	1/4-1/2 day	3-7 days	± 10 days	1-2 days	3-6 days	1-2 days
BOD Removal	85-90%	60-75%	90%	98%	85-90%	85-90%	85-95%
Application	Low Strength Wastes	General	Expansion of Existing Systems, Package Plants	Small Communities, Package Plants	High Organic Wastes, Resistant to Shock Loads	General, Wide Range of Wastes	Expansion of Existing Plants, Must be Used Near Economical Source of Oxygen



EFFLUENT CHANNEL
MECHANICAL AERATORS
INFLUENT DISTRIBUTION WASTE WATER FOR WASTE WATER AND RETURN SLUDGE
INFLUENT
EFFLUENT
SEDIMENTATION TANK
ADJUSTABLE WEIRS
RETURN ACTIVATED SLUDGE (RAS)
WASTE SLUDGE

FIGURE A-5. COMPLETE MIX ACTIVATED SLUDGE PROCESS

A complete mix activated sludge plant can function equally as well, if not better, without primary clarification as with primary clarification to provide greater than 90-95 percent BOD removals and highly nitrified effluents.[5] However, the use of primary clarifiers prior to the activated sludge aeration basin can provide dampening or surge control of the diurnal variations in wastewater flows.

Several environmental factors affect the growth of microorganisms. The most important are temperature, pH, oxygen supply, availability of nutrients, and type of substrate.

One of the significant factors to be considered in the selection of a process utilizing microorganisms for degradation of organic wastes is the effect of temperature on process performance. The temperature effect on the reaction rate of a biological process can be expressed by the relationship

$$K_T = K_{20}\ \theta^{(T-20)}$$

where K_T = reaction rate at T°C,

K_{20} = reaction rate at 20°C,

θ = temperature activity coefficient, and

T = temperature, °C.

The coefficient θ for microbial activity expressed as respiration rate has been reported as 1.074 by Wuhrmann[167] and 1.085 by Eckenfelder.[130] It has been shown, however, that this coefficient varies markedly with the type of process and its operation. Eckenfelder[55] states that the wide variation of θ is due to its dependency on the diffusion of oxygen into biological flocs, which in turn affects the degree of oxidation. At low temperatures, a low oxygen utilization rate permits development of a larger aerobic zone (boundary layer surrounding the floc) and biological flocs are mostly aerobic. At high temperatures, the increased respiration rate depletes oxygen rapidly causing the aerobic zone surrounding the floc to be thin. In fact, some portions of the floc may be anaerobic in the latter case.[55]

Temperature not only influences metabolic activity of microorganisms, but also has a profound effect on gas transfer rates and settling characteristics of biological solids. Oxygen is a slightly soluble gas in water, having a saturation value of approximately 9 mg/l at 20°C. The saturation value decreases with increases in water temperature. The following equation can be used to approximate the oxygen saturation at different temperatures.[168]

$$Cs = \frac{475 - 2.65\ S}{33.5 + T}\ P$$

where Cs = oxygen saturation concentration, mg/l

S = water salinity, mg/l

T = temperature, °C

$$P = \frac{\text{barometric pressure, mm Hg}}{760}$$

Table A-4 illustrates the effect of temperature on oxygen saturation at various elevations.

The pH of a biological culture medium has a direct influence on microbial growth. Most biological treatment systems operate optimally in a neutral environment, or within a pH range of 6.5 to 8.5. Some microorganisms are extremely sensitive to changes in pH, while others are quite tolerant. The pH has an overall affect on biological oxidation by influencing enzymatic activity. Municipal wastewaters have a large buffering capacity which resists changes in pH and thus maintains the near neutral pH range. However, this is not the case for industrial wastewaters.

Keefer and Meisel[169] found the optimum range for treating domestic sewage to be pH 7.0 to 7.5, and found treatment efficiency still effective in the pH range 6.0 to 9.0. At pH 4.0, the process was only 43 percent as effective and at pH 10.0, only 54 percent as effective.

Most biological waste treatment involves the utilization of aerobic bacteria for the stabilization of waste organics. Aerobic bacteria require molecular, dissolved oxygen for respiration. Atmospheric oxygen becomes available to the microorganisms as it is dissolved into the liquid medium that surrounds the cells. As previously mentioned, the solubility of oxygen is temperature dependent.

Photosynthesis carried out by aquatic plant cells supplies a significant portion of the dissolved oxygen in many surface waters. However, in most biological treatment systems the population of aquatic plants (algae) is unstable; thus oxygen must be supplied by artificial means.

Efficient and successful biological oxidation of organic wastes requires a minimal quantity of nitrogen and phosphorus for the

TABLE A-4

SOLUBILITY OF OXYGEN (MG/L) AT VARIOUS TEMPERATURES AND ELEVATIONS

(Based on Sea Level Barometric Pressure of 760 mm Hg)

Temperature (°C)	Elevation, Feet above Sea Level						
	0	1000	2000	3000	4000	5000	6000
0	14.6	14.1	13.6	13.2	12.7	12.3	11.8
2	13.8	13.3	12.9	12.4	12.0	11.6	11.2
4	13.1	12.7	12.2	11.9	11.4	11.0	10.6
6	12.4	12.0	11.6	11.2	10.8	10.4	10.1
8	11.8	11.4	11.0	10.6	10.3	9.9	9.6
10	11.3	10.9	10.5	10.2	9.8	9.5	9.2
12	10.8	10.4	10.1	9.7	9.4	9.1	8.8
14	10.3	9.9	9.6	9.3	9.0	8.7	8.3
16	9.9	9.7	9.2	8.9	8.6	8.3	8.0
18	9.5	9.2	8.7	8.6	8.3	8.0	7.7
20	9.1	8.8	8.5	8.2	7.9	7.7	7.4
22	8.7	8.4	8.1	7.8	7.7	7.3	7.1
24	8.4	8.1	7.8	7.6	7.3	7.1	6.8
26	8.1	7.8	7.6	7.3	7.0	6.8	6.6
28	7.8	7.5	7.3	7.0	6.8	6.6	6.3
30	7.5	7.2	7.0	6.8	6.5	6.3	6.1
32	7.3	7.1	6.8	6.6	6.4	6.1	5.9
34	7.1	6.9	6.6	6.4	6.2	6.0	5.8
36	6.8	6.6	6.3	6.1	5.9	5.7	5.5
38	6.6	6.4	6.2	5.9	5.7	5.6	5.4
40	6.4	6.2	6.0	5.8	5.6	5.4	5.2

synthesis of new cells. In addition, trace quantities of several other elements such as potassium and calcium are required. These trace elements are usually present in natural waters in sufficient quantities to satisfy requirements for microbial metabolism. However, nitrogen and phosphorus are sometimes deficient in wastewater substrates and cause reductions in removal efficiencies of biological treatment systems. In such cases, nutrients must be added to supplement those in the wastewater substrate. Nitrogen should be added as a supplement in the form of ammoniacal nitrogen because nitrite and nitrate nitrogen are not readily available for microbial usage. Several soluble phosphorus salts which are readily assimilated by microorganisms are available. Generally, a BOD:N:P ratio of 100:5:1 is thought to be the optimum ratio of nutritional requirements for microorganisms utilized in biological waste treatment. (BOD is the term applied to signify the strength of organics in wastewater and is defined generally as the amount of oxygen required by microorganisms to biologically oxidize a given quantity of organics. The stronger the organic waste material, the higher the BOD.)

Microorganisms have enormous ability to acclimate themselves to materials which are thought to be toxic to them. Acclimation is accomplished over a lengthy period by adding increasing amounts of the material and letting the microorganisms come to equilibrium at each increasing incremental concentration. However, once acclimated to a certain concentration level, the microorganisms become extremely sensitive to rapid changes.

Phenolics and formaldehyde have been processed at concentrations up to 1,000 mg/l, and sulfides and cyanides up to 100 mg/l.[130] Metal ions, often thought to be highly toxic, have been successfully treated at concentrations of 10 mg/l.[130]

Aeration equipment and sludge return pumps are the major pieces of equipment dependent on a constant source of power. Therefore, providing continuous treatment will require an emergency standby power supply.

Design Assumptions

A BOD loading factor of 50 pounds/1000 cubic feet, a return activated sludge flow of 100 percent, and a 6 hour aeration period were assumed for the sizing and cost purposes of this report. In addition, primary sedimentation and mechanical aeration was to be provided. Design flows are based on the average daily flow.

Secondary sludge production is a complex function of several variables including suspended solids and BOD removal efficiencies in both primary and secondary treatment, soluble BOD and other factors. For the type and quality of wastewater anticipated, secondary sludge yield should be about 0.7 pounds per pound of BOD applied to the secondary system. Therefore, it is anticipated that secondary sludge production will be approximately 1000 pounds per one million gallons of wastewater treated.

ACTIVATED SLUDGE WITH CHEMICAL ADDITION

Process Description

Chemical addition to the activated sludge process has been found to be an effective method for adding nutrient removal capability to an efficient biological treatment system. The combination of the two processes constitutes a biological-chemical process designed to accomplish two purposes: the biological conversion of organic matter to particulate form and the chemical coagulation of this particulate matter with the concomitant precipitation of phosphorous. Each process is designed to be highly efficient at its particular task. Furthermore, the marriage of the two processes reinforces the advantages of each step while minimizing their disadvantages.

This biological-chemical process is particularly well adapted for application to existing activated sludge wastewater treatment plants since it makes maximum use of existing facilities, thus minimizing capital expenditures. Biological-chemical processes may also be applied to newly constructed treatment facilities to achieve effluent quality better than that expected from conventional secondary treatment.

The biological aspects of the combined treatment system are essentially the same as those described in the previous discussion of the activated sludge process. The chemical aspects typically require the addition of either iron or aluminum salts near the effluent end of the aeration basin. Lime is not employed since the resulting rise in pH is not compatible with efficient biological activity. A discussion of the coagulation process pertinent to the chemical aspects of this alternative is presented later in the report.

Activated sludge with chemical addition suffers the same process sensitivities as the basic activated sludge process as described earlier. The use of the coagulent, however, affords greater flexibility in the ability to remove suspended solids at high loading rates. Combined biological-chemical treatment produces approximately twice the sludge produced in a simple activated sludge unit.

Flexibility should be incorporated into the design of these systems so that reasonable changes from predicted values can be incorporated into plant operation without adversely affecting the result obtained. The following parameters must be evaluated in order to achieve an economical design that will provide the flexibility and capability to meet the effluent requirements established for the plant:

- Flow - design for average flow rates with due consideration of peak flow and daily, weekly and monthly variations.
- Phosphorus concentration - variation in concentration with time is important as are the relative amounts of ortho and complex, soluble and insoluble phosphorus.
- Alkalinity - higher alkalinity systems (125 mg $CaCO_3$/l or above) tend to favor usage of alum. If alkalinity is below 125 mg $CaCO_3$/l, sodium aluminate would probably be the chemical of choice although alum plus lime should also be considered.
- pH - related to alkalinity. If pH is 7.0 or above, alum is preferred whereas low pH would favor usage of sodium aluminate.
- Sulfate - addition of appreciable amounts of sulfate to wastewaters already high in sulfate concentration or where effluents are to be discharged to a stream used for potable water sources may be undesirable. In this event, sodium aluminate would probably be the chemical of choice.

Liquid chemical handling and feeding systems are generally easier to operate and maintain than are dry feed systems. However, transporatation costs and inaccessibility to liquid chemical sources may dictate use of dry chemicals in some instances. Chemical manufacturers should be consulted for detailed recommendations on chemical storage and unloading facilities. Provision should be included for measuring the amount of chemical fed.

The point of chemical addition should be located as near to the effluent end of the aeration tank as is practical. Because of the severe pH shock which occurs when alum was added directly into the effluent channel, it is suggested that addition be made into the aeration tank in order to take advantage of the greater buffering capacity at that point. Some deterioration in effluent quality can be expected as the point of addition is moved toward the influent end.

No special solids handling equipment or requirements are necessary for handling and disposal of the sludges resulting from chemical-biological treatment. Flexibility in pumping units should be sufficient to handle the greater weight of solids and volumes of sludges which result from chemical-biological treatment. Sludge weights approximately twice those obtained without chemical addition can be expected.

Dewatering and disposal of the chemical-biological sludges should not present any unusual problems. Dewatering of sludges may be accomplished by any of the normally employed unit processes. It is unlikely that recovery of the precipitating chemical will offer any economic advantage except under unusual circumstances.

Different wastewaters will undoubtably require different Al/P ratios to achieve a given effluent phosphorus concentration and these relationships can only be developed from actual plant operating data.

Control of mixed liquor suspended solids must take into consideration the much lower percentage of volatile solids in the chemical-biological system. The mixed liquor volatile suspended solids should be maintained at the necessary level to achieve the desired organic loadings. Once the system has reached a balance, control can be based on total suspended solids with regular checks on volatile solids so that any changes can be incorporated into sludge wasting schedules.

Design Assumptions

Alum was selected as the chemical coagulant to be added at the effluent end of the complete mix activated sludge process. The alum dose was 150 mg/l, resulting in a 90 percent phosphorus removal. The amount of sludge (dry solids basis) produced was assumed twice that from a normal activated sludge plant or 2,500 pounds per million gallons treated. A liquid chemical feed system was assumed. Sludges were handled and disposed as normal activated sludge.

EXTENDED AERATION

Process Description

The large amount of waste sludge that must be disposed of is a major limitation to all activated sludge systems. The extended aeration process was developed in an attempt to completely oxidize the waste sludge within the system.

The extended aeration process operates in the endogenous growth phase of the bacterial growth curve. The endogenous growth phase is utilized in the extended aeration process with low concentrations of substrate in contact with a relatively high number of organisms for long periods of time, thus theoretically resulting in complete oxidation of the incoming wastes. Solids are retained for a relatively long period (high sludge age) to provide for stabilization of the sludge. A sludge age of 30 days usually provides a well-stabilized sludge. Excess sludge is generally wasted in the form of suspended solids in the effluent. Suspended solids in the effluent are normally less than 70 mg/l. These solids are generally sufficiently stabilized so as not to create an excessive oxygen demand upon discharge to surface waters. A schematic of a typical extended aeration system is shown in Figure A-6.

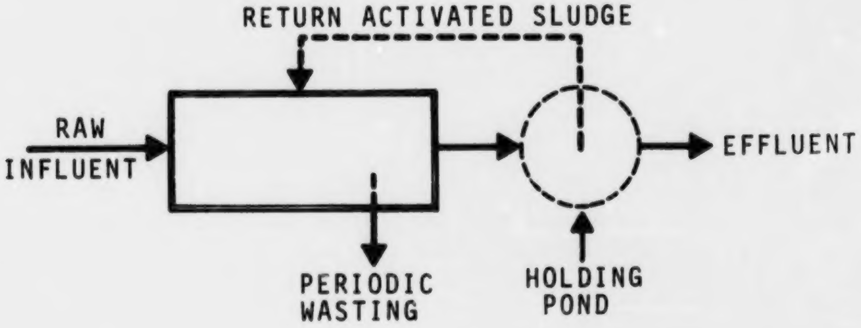


FIGURE A-6. EXTENDED AERATION PROCESS

The extended aeration system has become the standard for waste treatment in small housing subdivisions, schools, industrial plants, institutions, shopping centers, recreation resort areas, and small communities that are located beyond municipal sewerage systems.[185-189]

Treatment efficiencies for extended aeration plants, if properly operated, are generally greater than 90 percent. At temperatures above 60°F (15.5°C) sludge growth is approximately balanced by losses of relatively inert suspended solids which are carried out of the system in the effluent. These inert suspended solids contribute little BOD.

As mentioned previously, temperature has an effect on microbial metabolism, and thus the degradation of wastes. Decreasing temperatures decrease the metabolism rate of microorganisms. It has been reported that low loaded extended aeration systems operating at temperatures of 5°C to 10°C showed good removal efficiencies.[190] Extended aeration at reduced BOD loadings with resultant long aeration times can compensate for the low metabolism rate of the microorganisms.

Successful operation of an extended aeration plant at temperatures down to 2°C has been reported[190] indicating low temperature activated sludge treatment is feasible.

Extended aeration is characterized by loading factors that are much lower than those associated with the short-term aeration processes. Extended aeration typically operates at loading factors ranging from about 0.05 to 0.20 lb BOD/day/lb volatile suspended solids (VSS). The volumetric loading is generally about 20 lb BOD/day/1000 ft^3 of aeration tank capacity. Detention time in the process is usually about 24 hours.

One important consideration in extended aeration is thorough mixing of the biological sludge and the raw waste. The oxygen requirements of the microorganisms in the biological sludge are very low, about 10 to 15 mg/l/hr. This is about 25 percent of the oxygen requirement at the head end of a conventional activated-sludge aeration tank.

Several environmental factors affect the growth of microorganisms. The most important are temperature, pH, oxygen supply, availability of nutrients and type of substrate.

One of the most significant factors to be considered in any process utilizing microorganisms for degradation of organic wastes is the effect of temperature on process performance.

Biochemical reactions, in general, follow the van't Hoff rule of doubling of reaction rate for a 10°C increase in temperature, over a restricted temperature range. Studies with activated sludge have shown the reaction rate to be more than doubled for a 10°C rise in temperature, as shown in Figure A-7.[191]

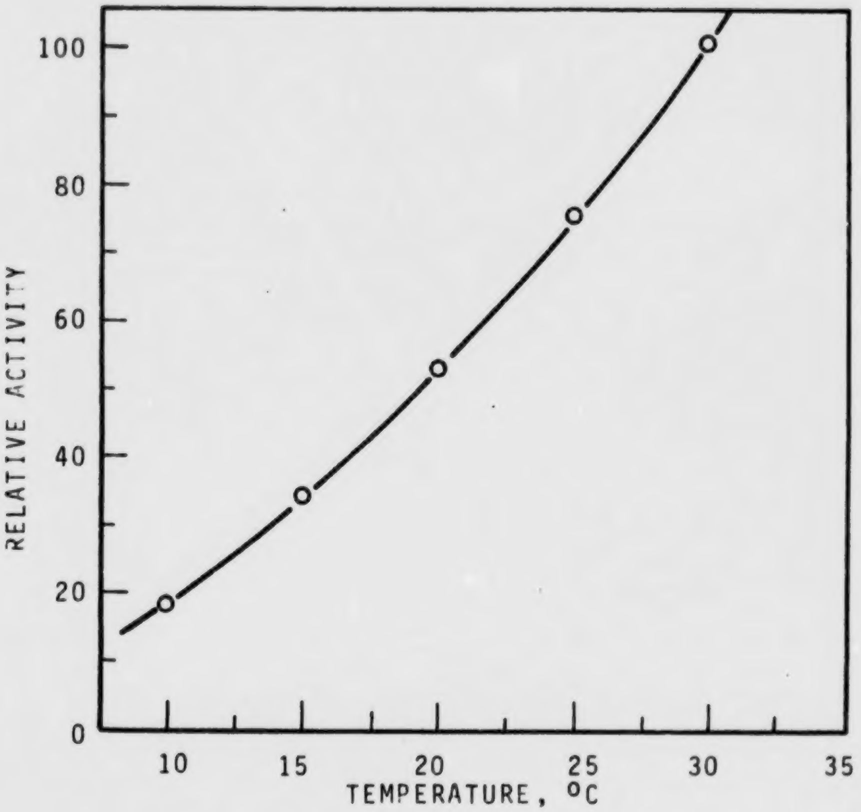


FIGURE A-7. EFFECT OF TEMPERATURE ON ACTIVITY OF ACTIVATED SLUDGE AS MEASURED BY OXYGEN REQUIREMENTS PER UNIT TIME[191]

Ultimately, however, a maximum temperature is approached at which reaction rate begins to decline. This has been credited to a denaturization of enzymes or continually greater difficulty for the organism to produce enzymes.[191] The overall relation is analogous to that shown in Figure A-8 for the enzyme malt amylase.

The pH of a biological culture medium has a direct influence on microbial growth. Most biological treatment systems operate optimally in a neutral environment, or within a pH range of 6.5 to 8.5. Some microorganisms are extremely sensitive to changes in pH, while others are quite tolerant. The pH has an overall effect on biological oxidation by influencing enzymatic activity. Biological utilization of organic material involves a series of enzyme catalyzed reactions. Each enzyme is catalytically active within a limited range of pH. For example, the optimum range for the activity of pepsin is between pH 1.5 and 2.5; for trypsin, between pH 8 and 11; for salivary amylase, between pH 6.7 and 6.8.[192] In a heterogeneous system such as treatment of a municipal wastewater, involving a whole sequence of enzyme reactions and a good buffering capacity, a mean pH range generally is established. This is not necessarily true for industrial wastewater.

Keefer and Meisel[169] found the optimum range for treating domestic sewage to be pH 7.0 to 7.5, and found treatment efficiency still effective in the pH range 6.0 to 9.0. At pH 4.0, the process was only 43 percent as effective and at pH 10.0, only 54 percent as effective.

Efficient and successful biological oxidation of organic wastes requires a minimal quantity of nitrogen and phosphorus for the synthesis of new cells. In addition, trace quantities of several other elements such as potassium and calcium are required. These trace elements are usually present in natural waters in sufficient quantities to satisfy requirements for microbial metabolism. Generally, a BOD:N:P ratio of 100:5:1 is thought to be the optimum ratio of nutritional requirements for microorganisms utilized in biological waste treatment.

Biological activity will also be effected by the presence of various toxic substances. Heavy metal content in general should not exceed 10 ppm. Specific work in Cincinnati suggests 10 ppm chromium, 1 ppm copper, 1-2.5 ppm nickel, or 5-10 ppm zinc. Cyanides, phenols and detergents may also cause disturbances in active biota, but acclimation to steady state doses allows treatment of relatively high concentrations. Slug loads of these materials poses the greatest threat to effluent quality.

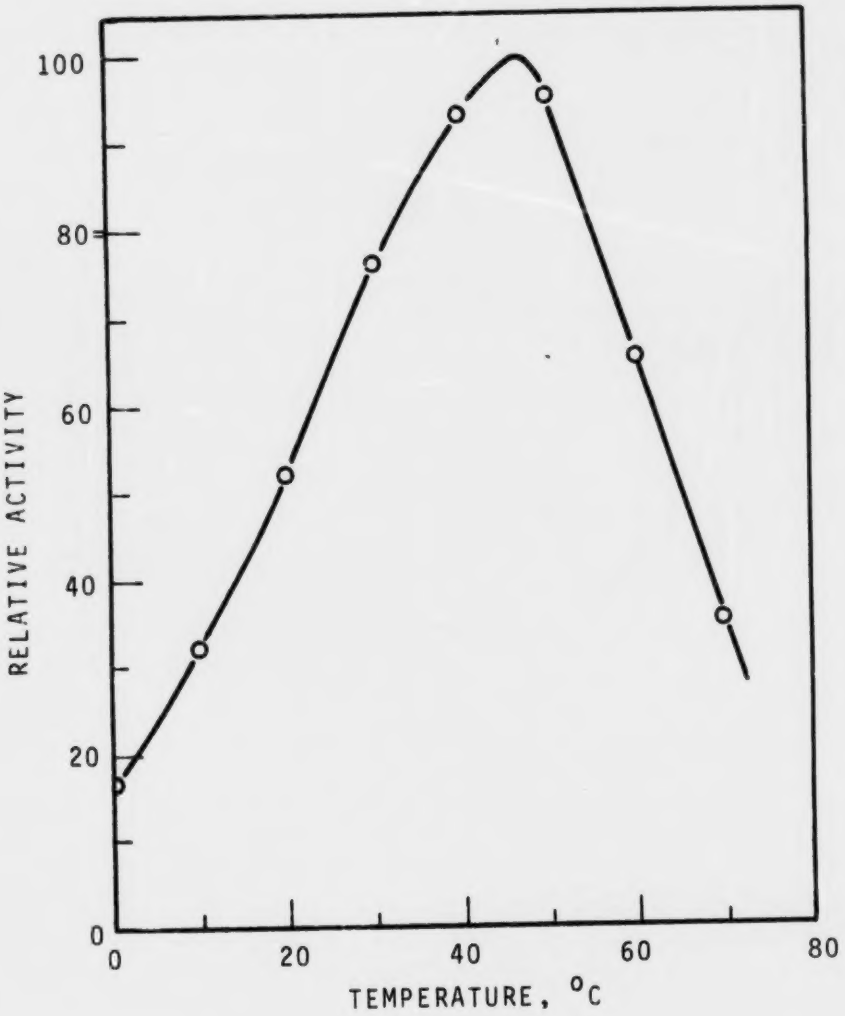


FIGURE A-8. EFFECT OF TEMPERATURE ON THE ACTION OF MALT AMYLASE WHEN HYDROLYZING STARCH TO GLUCOSE[191]

Power failure can effectively shut down extended aeration plants due to their reliance on mechanical aerators. Other operational sensitivities are similar to those noted for the activated sludge process.

Design Assumptions

For the purposes of the profiles presented in this report, a loading rate of 0.05 lbs BOD/day/lb volatile suspended solids (VSS) was assumed. Volumetric loading was set at 20 lbs BOD/day/1000 cu ft. Provision was made for a 24 hour aeration period with 100-150 horsepower per million gallons utilized. Biological solids are aerobically digested leaving a minimum amount to be handled. Solids were wasted at 900 dry pounds per million gallons of wastewater treated.

TRICKLING FILTER PROCESS

Process Description

The trickling filter process consists of a fixed bed of coarse, rough material over which wastewater is intermittently or continuously distributed in a uniform manner by a flow distributor. Microorganisms grow on the surface of the filter media forming a biological or zoogleal slime layer. Wastewater flows downward through the filter, passing over the layer of microorganisms. Dissolved organic material and nutrients in the wastewater are taken up by the zoogleal film layer for utilization by the microbial population. Oxidized end products are released to the liquid and collected in the underdrain system for discharge via the effluent channel. Aerobic conditions are maintained by air passing through the filter bed induced by the difference in specific weights of air on the inside and outside of the bed. A trickling filter will operate properly as long as the void spaces are not clogged by solids or excessive growth of the zoogleal film layer. The zoogleal film layer grows and gradually increases in thickness to the point that hydraulic shear force from the downward flow of wastewater causes portions of the film layer to slough off the filter media. This periodic sloughing of filter film is discharged to secondary clarification units.

Trickling filters may be classified as low, intermediate, high or super-rate filter systems. The distinction between these systems is usually based on the hydraulic and organic loading to the filter. Low rate filters operate at hydraulic loadings of 2-4 MGD per acre with organic loadings of 10 to 20 lbs BOD/1000 cu ft/day. Figure A-9 is a flow sheet of a low rate filter. Generally, low rate filters do not use recirculation of effluent to maintain a constant hydraulic loading, but use either

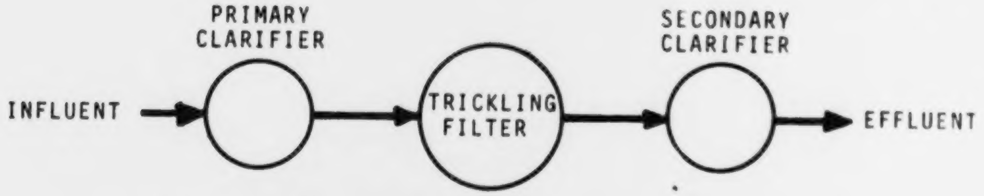

PRIMARY
CLARIFIER
SECONDARY
CLARIFIER
INFLUENT
TRICKLING
FILTER
EFFLUENT

FIGURE A-9. LOW RATE SINGLE STAGE FILTER

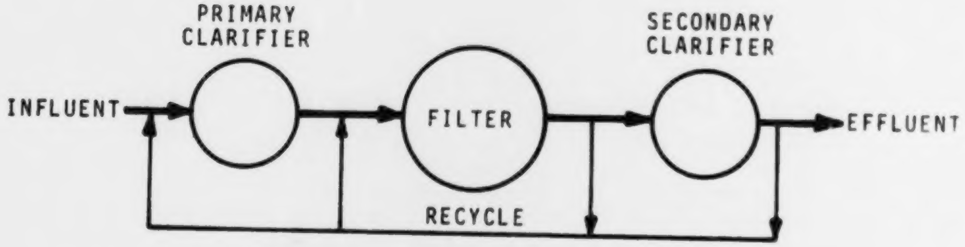

PRIMARY
CLARIFIER
SECONDARY
CLARIFIER
INFLUENT
FILTER
EFFLUENT
RECYCLE

FIGURE A-10. INTERMEDIATE RATE FILTER WITH ALTERNATE RECYCLE FLOW PATTERNS

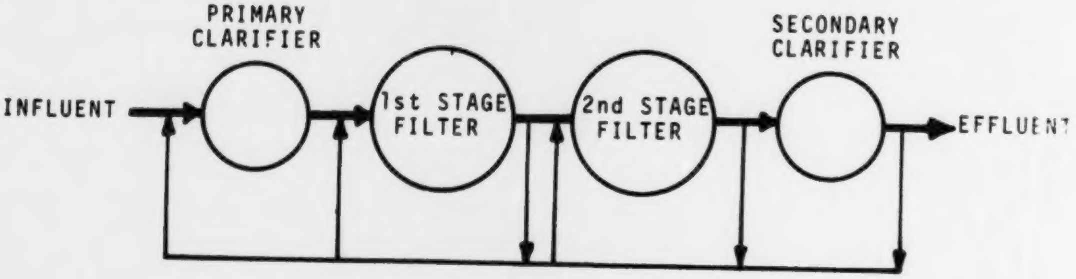

PRIMARY
CLARIFIER
SECONDARY
CLARIFIER
INFLUENT
1st STAGE
FILTER
2nd STAGE
FILTER
EFFLUENT

FIGURE A-11. HIGH RATE, TWO STAGE TRICKLING FILTER WITH ALTERNATE RECYCLE FLOW PATTERNS suction-level controlled pumps or a siphon for an intermittent water application.[20] Intermittent dosing may become a problem if the dosing interval is long (greater than one or two hours) since the filter slime layer may dry out.

Intermediate rate trickling filters are generally designed to operate at hydraulic loadings of 4 to 10 MGD/acre with corresponding organic loadings ranging from 15 to 30 lbs BOD/1000 cu ft/day.[20] These loading rates include recirculation of a portion of the effluent, which is often practiced with these filters. Normally these filters are single stage filters. Figure A-10 illustrates a flow sheet for an intermediate rate filter, with various alternative patterns for recycle that are now, or have been used in the past.

High rate trickling filters operate at hydraulic loadings of 10 to 30 MGD/acre and organic loadings of up to 90 lbs BOD/ 1000 cu ft/day. These loadings include recirculation of a portion of the effluent to maintain a relatively constant hydraulic loading. The higher loadings applied to a single stage filter in the high rate mode generally result in lower BOD removal efficiencies. To improve BOD removal efficiency, a second stage is added to treat the effluent from the first stage. Figure A-11 shows a flow sheet of a typical two stage filter with various alternatives for recirculation.

Super rate trickling filters have evolved as a result of the development of various types of synthetic filter media. Past experience has indicated that hydraulic loadings of 150 MGD/ acre, including recirculation, may be accommodated in super rate filters. The flow configuration for super rate systems is similar to that of high rate filters.

Several environmental and physical factors affect the performance of trickling filters as they do all biological systems. Environmental factors such as temperature, pH, oxygen supply, nutrients and substrate are discussed in the activated sludge process descriptions. Physical factors include the type of media and depth, hydraulic and organic loading, and recirculation.

Diurnal fluctuations in hydraulic and organic loads cause considerable problems to trickling filters, especially high organic loads or extremely low hydraulic loads. High organic loads (shock loads) may be deleterious to the organisms in the zoogleal slime layer. Low hydraulic loads may allow the slime layer to become dry.

It was thought that recirculation of effluent back to the filter would help minimize these two effects.[176] In addition, most investigators agree that recirculation aids in removal efficiencies to a point. Chipperfield[170] feels that recirculation of partially treated effluent to the top of the filter ceases to have any beneficial effect on removal of BOD when the hydraulic loading is equal to or greater than the minimum wetting rate. Minimum wetting rate is defined as the minimum irrigation rate (volume applied/unit cross-sectional area of the filter) below which adequate wetting of the surface of the filter pack media does not occur. The surface slime layer must be kept wet to maintain a viable population of organisms, thus a portion of the effluent should be recycled to maintain hydraulic equilibrium above this "minimum wetting rate." Recycle becomes very important at periods of low influent flows. Culp[171] compared the effectiveness of two high rate trickling filter recirculation patterns and found little difference.

Ventilation of trickling filters is essential to the maintenance of aerobic conditions throughout the filter media. In the past the depth of conventional rock filled trickling filters was limited by the amount of air that could be forced through the filter; depths in excess of 9-10 feet caused anaerobic conditions in the lower portion of the filter. Hence, most conventional trickling filters are 3-8 feet deep, normally averaging 6 feet.[31]

Trickling filter media in the past generally consisted of crushed rock materials such as granite, slag, and gravel. Rock materials normally have specific surface areas of 10-12 square feet per cubic foot and void spaces of approximately 50 percent. Conventional rock-filled trickling filters are subject to certain disadvantages. These include the large land area required, relatively high construction costs, and tendency of void spaces to become clogged at excessive organic or hydraulic loading rates causing restriction of both air and liquid flow resulting in a condition known as "ponding."

Consideration of these disadvantages stimulated investigation of new types of filter media. Investigations have centered around the use of various types of artificial media to replace the conventional rock type materials. A trickling filter packing material must meet the following requirements.

- Material must be biologically inert and capable of supporting the growth of a biological film layer on its surface.

- Configuration and nature of the material must allow a thin, uniform distribution of liquid (wastewater) over its entire surface.

- Material installed as filter media should have a relatively high percentage of void spaces to allow for adequate passage of air and water throughout the filter. Sloughing of solids downward through the filter must be unhindered.

- Material must be chemically stable, not degraded in the presence of solvents, organic chemicals or biologically secreted substances.

- Material must be structurally able to support considerable weight for long periods without extraneous support.

- Material must be economically competitive with other types of trickling filter media.

Table A-5 compares the physical properties of several natural and artificial types of filter media. Two properties of significant interest are the specific surface area and the percentage of void spaces. Plastic materials have been fabricated having specific surface areas from 25 to 80 square feet per cubic foot[86,87] and void spaces of 94-98 percent. If these larger surface areas can actually be utilized, that is, provided with sufficient substrate and oxygen supply and kept free of excess sludge, greater purification efficiencies may be expected. It has been shown[170] that plastic type filter media with its large percentage of void spaces allows free passage of air to depths in excess of 25 feet. Plastic materials are light in weight and this, together with the large surface areas per volume and high percentage of void spaces, combines to give new freedom in trickling filter design. Since plastic materials are light in weight, trickling filters utilizing plastic media may be constructed to heights of 30 to 40 feet without the massive concrete support/underdrain systems required of conventional rock type materials.[31,170] A trickling filter constructed in tower form with plastic media for the treatment of a given volume of wastewater will require considerably less land area than a filter constructed with conventional rock materials.

TABLE A-5

PHYSICAL PROPERTIES OF VARIOUS TRICKLING FILTER MEDIA[20]

Media Type	Nominal Unit Size (inches)	Unit Weight (lbs/cu ft)	Specific Surface Area (sq ft/cu ft)	Void Space (%)
Plastic	20 X 48	2-6	25-30	94-97
Del-pak Redwood	47 1/2 X 47 1/2 X 35 3/4	10.3	14	--
Granite	1-3	90	19	46
Granite	4	--	13	60
Blast Furnace Slag	2-3	68	20	49

Two major factors affecting the performance of a trickling filter are its hydraulic and organic loading rates. As previously mentioned, these factors are the bases for classification as to the type of filter, i.e., high or low rate. An attempt was made to correlate the efficiency of various trickling filters with their corresponding hydraulic and organic loading rates.[20] The effects of hydraulic loading rates for stone media are shown in Figure A-12 and for plastic media are shown in Figure A-13. Two facts appear in comparing these figures: first, the range of applied hydraulic loading of the plastic media is greater than five times that of the stone media; and secondly, it appears that increasing hydraulic loading causes reductions in BOD removal efficiencies. The effect of the organic loading rates for stone media are shown in Figure A-14 and for plastic media in Figure A-15. These show that increases in organic loading have little effect in reducing BOD removal efficiencies. Rincke and Wolters[172] and Chipperfield[170] also noted similar effects. However, in two separate studies using different sized stone media, Meltzer[174] and Krige[175] concluded that increased organic loadings had no effects on removal efficiencies of smaller media (3/4" to 1 1/2" stones), but that larger media (2" to 4" stones) showed a significant decrease in removal efficiencies with increased organic loadings.

Very heavy organic loading of trickling filters will cause excessive growths of the zoogleal slime layer to a point where the void spaces are filled and "ponding" occurs. This "ponding" halts the flow of liquid through the filter with subsequent reductions in BOD removal efficiencies. Plastic media, with its larger percentage of void spaces, will not be affected as easily as stone media filters.

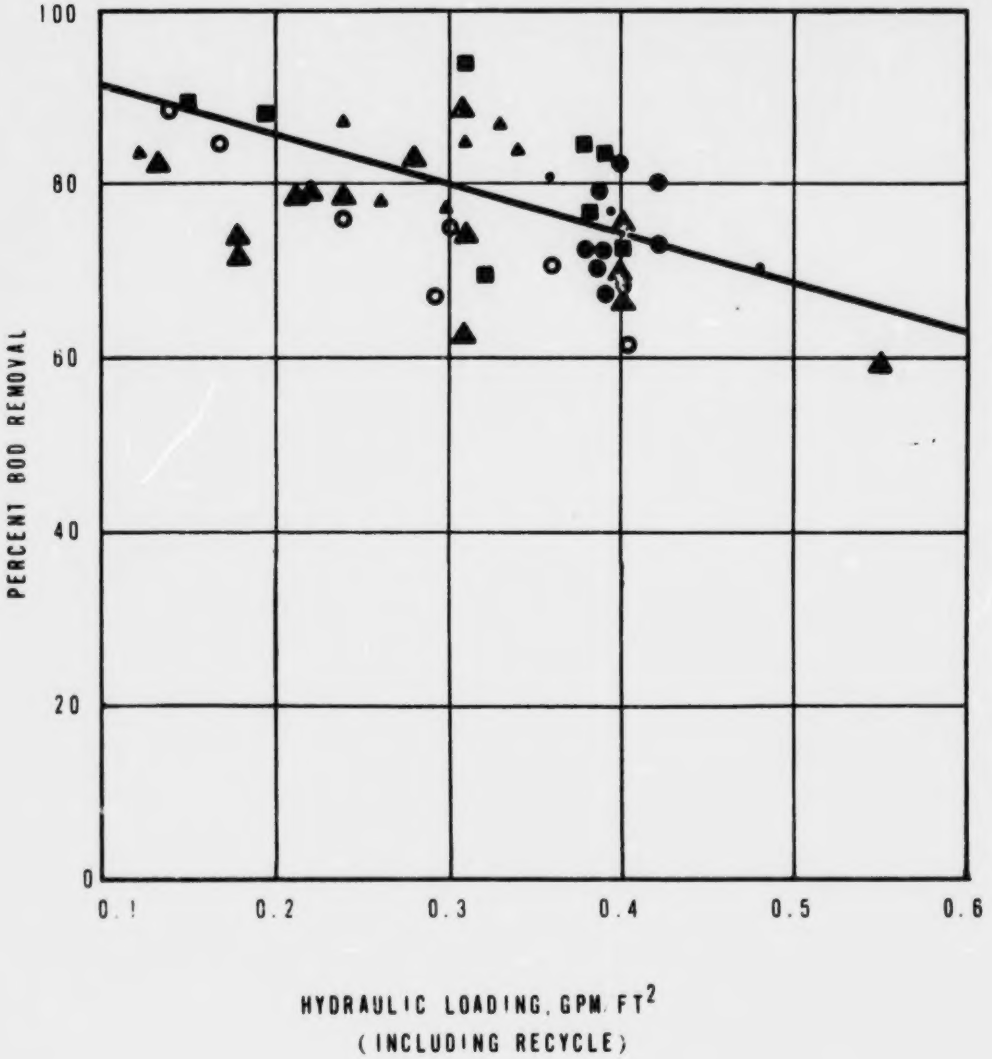


FIGURE A-12. EFFECT OF HYDRAULIC LOADING ON STONE MEDIA TRICKLING FILTER PERFORMANCE[20]

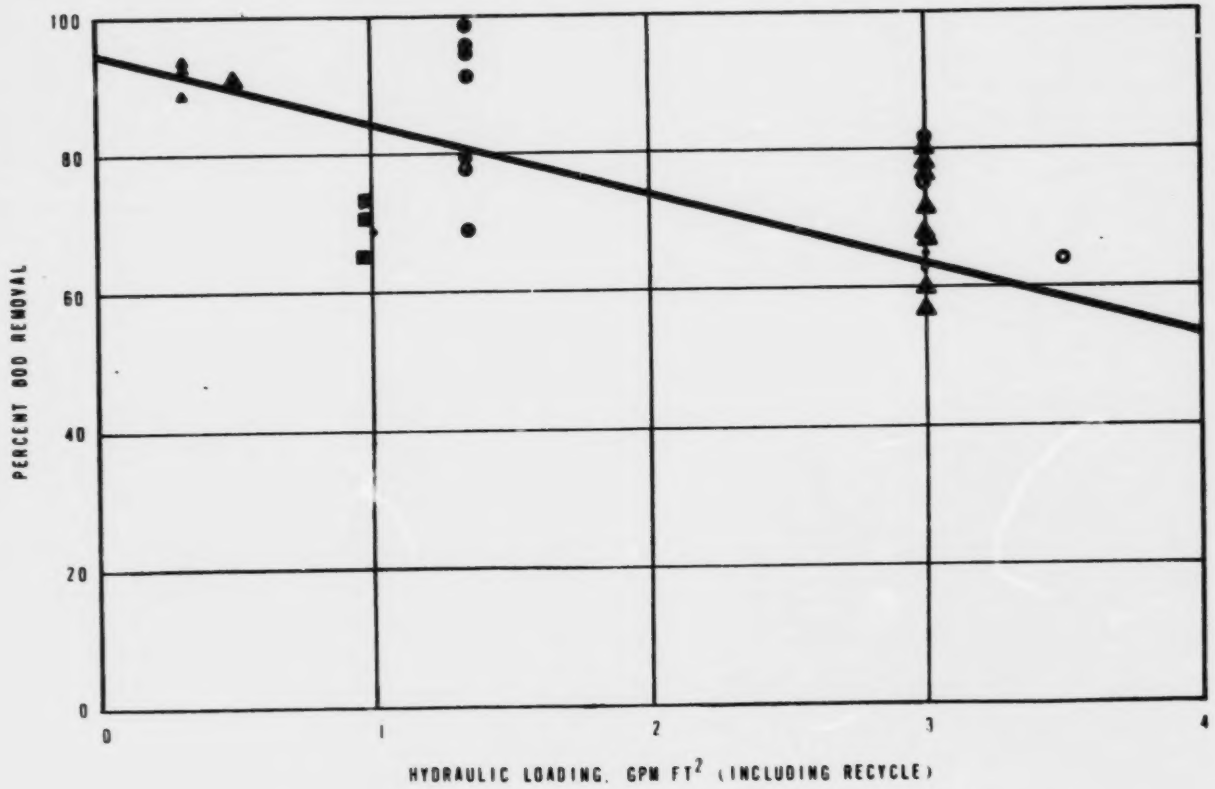


FIGURE A-13. EFFECT OF HYDRAULIC LOADING ON PERFORMANCE OF PLASTIC MEDIA TRICKLING FILTERS[20]

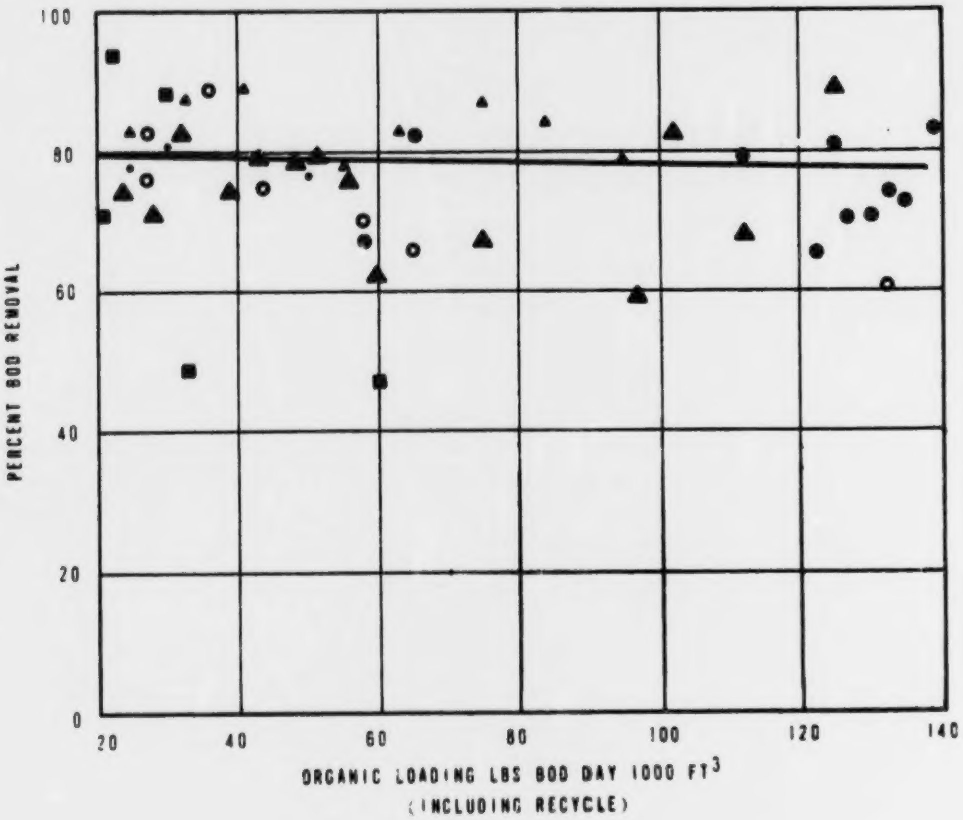


FIGURE A-14. EFFECT OF ORGANIC LOADING ON STONE MEDIA TRICKLING FILTER PERFORMANCE[20]

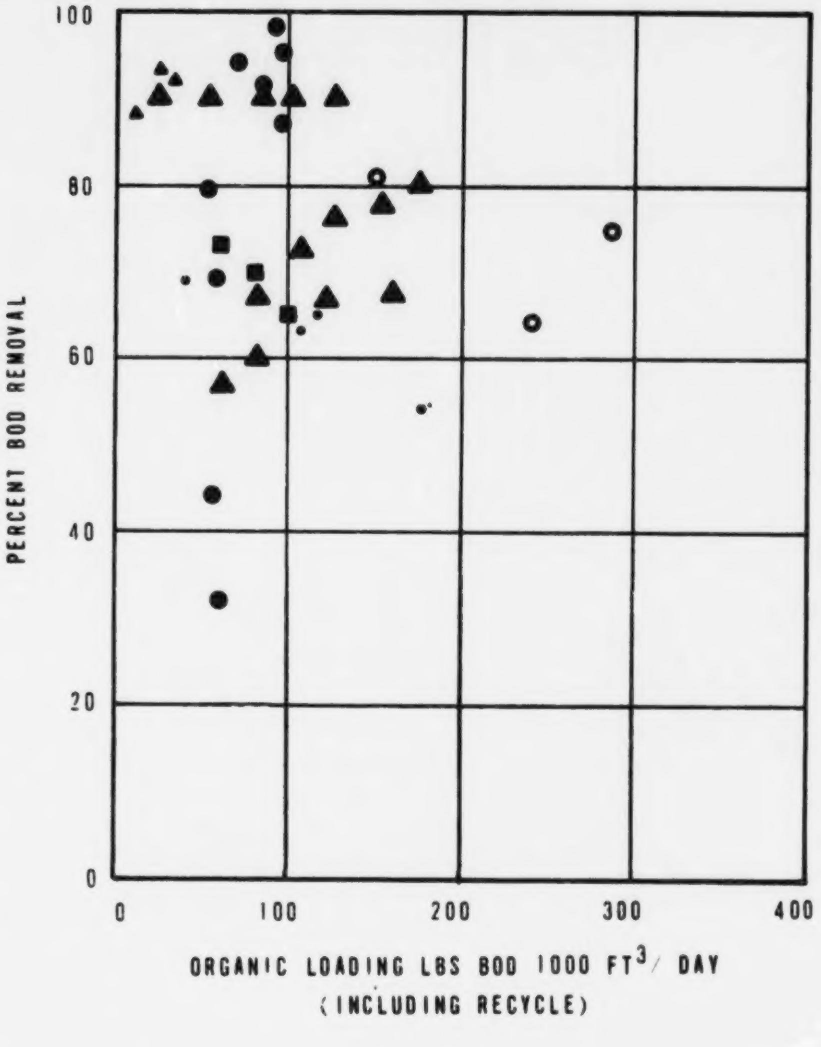


FIGURE A-15. EFFECT OF ORGANIC LOADING ON PERFORMANCE OF PLASTIC MEDIA TRICKLING FILTERS[20]

Design Assumptions

For the design and cost purposes of this report a high rate two stage trickling filter with an organic loading rate of 50 lbs BOD/1000 cu ft and a hydraulic loading rate of 20 MGD/acre were assumed. The average daily flow was used as the design flow. Influent wastewater characteristics are outlined in the introductory section of this report.

Conventional rock type materials were assumed as filter media for both trickling filters. The organic solids produced from a trickling filter result mainly from the sloughing of zoogleal slime layers from the filter media. It was assumed that 320 lbs (dry solids basis) of sludge would be produced from the treatment of one million gallons of wastewater.

FILTRATION

Process Description

Filtration is a unit process for the separation of solids from liquids. Solids are removed from the liquid during passage through some kind of network of wires, threads, fibers or other porous membranes such as woven fabric or filter paper, or porous beds of powdered or granular material such as diatomaceous earth or sand. The solids are retained by the filtering medium itself and/or by the solids already held or matted on the medium.

The development of the filter for solids removal took place in England in the mid-nineteenth century and was originally used to filter water for drinking purposes.[53] These early filters, using sand as a filtering media, were operated at relatively low flow rates (.04 to .12 gpm/ft^2 of filter area) and generally functioned satisfactorily on untreated English surface waters. However, these filters were not generally successful on untreated waters in the United States. This led to the development and use of chemical coagulation before sand filtration of the water.

Filters developed in the late nineteenth century in the United States were operated at much higher flow rates, ranging from 1 to 4 gpm/ft^2. The higher rates used in these filters meant less filter area and less capital investment to achieve the desired capacity. In the early to mid 1900's, wastewater filtration (using sand as the media) was implemented as a tertiary treatment process to remove solids from biologically treated wastewater. Since that time, more sophisticated and efficient filtration units have found widespread use in many wastewater treatment facilities.

The mechanisms involved in the removal of suspended or colloidal material from wastewater by filtration are complex and interrelated. The dominant mechanisms depend on the physical and chemical characteristics of the particulate matter and filtering medium, the rate of filtration, and the biological-chemical characteristics of the water. The mechanisms responsible for the removal of particulate matter will vary with each treatment system.

The processes by which solids are filtered from wastewater may be generally classified into two categories: adhesion and straining. Adhesion involves the physical-chemical process of particle adsorption on the surface of the filtering medium. As a particle approaches the surface of the filtering medium, or previously deposited solids on the medium, an attachment mechanism retains the particle. This attachment mechanism may involve electrostatic interaction, chemical bridging, or specific adsorption. It is the adhesion process which makes possible the removal of submicron particles during filtration by adsorption on the surfaces of the filter media.

The second process operation in removal of suspended particles is straining. Straining action takes place in the filter media at restrictions in the pores (minute openings in the filter). All particles larger than these openings will be trapped and held back. In granular filters, straining action takes place in the filter medium at restrictions in the pores formed where several particles of the filter medium come in contact. Smaller particles are also removed by straining in the depth of the filter (depth removal), but the fraction removed by straining decreases with the decreasing suspended solids particle size.

Secondary treated wastewater effluents may be "polished" by filtration to improve the quality of water discharged to surface receiving streams. Particulate matter, if not removed, would contribute to increased suspended solids, BOD and phosphorous concentrations, as well as increased turbidity of treated effluents. Granular media filtration can be the first step in an attempt to upgrade the effluent from a treatment plant to meet increased water quality standards. Alternatively, filtration can follow the coagulation-sedimentation processes in a physical-chemical treatment sequence.

A typical granular media filter is shown in Figure A-16. The wastewater is passed through one or several layers of granular material and suspended solids are removed by physical screening, sedimentation, and interparticle action.[182] Headloss increases until breakthrough or removal capacity is reached, and then the filter is cleaned by backwashing.

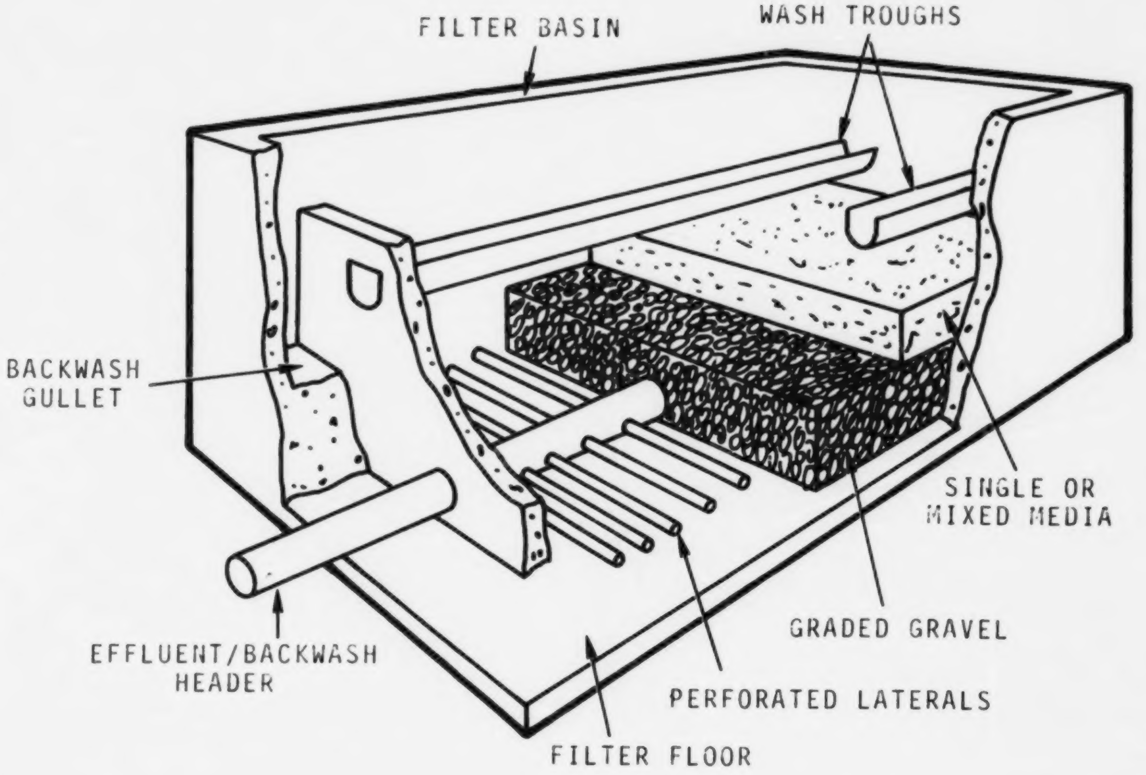

FILTER BASIN
WASH TROUGHS
BACKWASH GULLET
SINGLE OR MIXED MEDIA
GRADED GRAVEL
EFFLUENT/BACKWASH HEADER
PERFORATED LATERALS
FILTER FLOOR

FIGURE A-16. CUTAWAY VIEW OF A TYPICAL GRANULAR MEDIA GRAVITY FILTER[32,184]

Effective cleaning of the filter during backwash is essential to successful filter performance. In the past, it was felt that a 50 percent expansion of the filter media was required to sufficiently clean the particulate matter from the granular media during backwash. However, it is now recognized that optimum scouring of the particles results when the media are just suspended.[4] A backwash rate is required which will achieve the necessary bed expansion of 25-30 percent. However, the backwash rate is dependent on water temperature, specific gravity, and particle size of the filter media. Increased water temperature and specific gravity necessitate an increase in backwash flow rate.

Period of backwash is generally 5-8 minutes and requires approximately 2-5 percent of the filter throughout. Source of backwash water in wastewater treatment should be the filter effluent or other source which is low in suspended solids. The backwash water which must be reprocessed in the treatment plant represents a substantial volume. If directly recycled back to upstream treatment units, backwash volume is usually large enough in relation to design flow to cause hydraulic overload and upset of upstream treatment units. Thus, provisions should be made to store backwash water for subsequent controlled release back to the process stream.

Surface wash is required to insure effective cleaning of the filter media during backwash. Surface washing breaks up the clumps of media and floc or "mud balls" which are formed during filter operation. Proper surface washing causes circulation of the entire contents of the bed. Typical surface wash equipment consists of a rotating header with spray nozzles which direct high pressure (50-100 psi) wash water downward at a rate of approximately 1.0 gpm/sq ft, and are positioned about 1-2 inches above the normal height of the filter media. Surface wash water must be of relatively high quality so as not to plug the spray nozzles.

Backwashing causes the filter media to grade hydraulically, with the finest particles rising to the top of the bed and the coarser particles near the bottom.

Development of dual and multi-media filters have minimized the inherent sensitivity of rapid sand filters to high suspended solids concentrations. Dual and multi-media filters increase the effective filter depth to extend the work area and thereby increase the length of filter runs.

Dual media filters use a discrete layer of coarse coal above a layer of fine sand. The work area is extended, although it still does not include the full depth of bed. There is hydraulic grading within each layer of the filter, with fine particles of coal on top of the coal layer and the finest sand particles on top of the sand layer.

Mixed-media filters were developed in an attempt to approach ideal filtration. Three to four types of media are layered into the filter graded as to size and density, with coarse low density coal (sp. gr. about 1.0) on top, smaller regular density coal (sp. gr. about 1.6) and silica sand (sp. gr. about 2.6) in the middle two layers, and garnet sand or ilmenite (sp. gr. of 4.2 and 4.5, respectively) on the bottom layer.[183] These different media provide decreasing, coarse to fine, void gradation down through the filter. Large suspended particles in the wastewater are stopped near the surface with finer suspended solids being entrapped in bottom layers, thus providing full bed depth filtration.

Conley and Hsiung[184] presented techniques for determining depths of media for various applications. Table A-6 illustrates varying media designs for various types of application.

TABLE A-6

VARIATION IN MEDIA DESIGN FOR DIFFERENT APPLICATIONS[110]

	Depth of Media (inches)		
Type of Application	Garnet	Sand	Coal
Very Heavy Loading of Fragile Floc	8	12	22
Moderate Loading of Very Strong Floc	3	12	15
Moderate Loading of Fragile Floc	3	9	8

Generally, there is no one mixed-media filter depth which will be optimum for all wastewater filtration situations, typically most mixed-media filters are 24-30 inches deep.

Although a mixed-media filter can tolerate higher suspended solids loadings than can single media filters, it still has an upper limit of applied suspended solids at which economically long runs can be maintained. With activated sludge effluent, filter runs of 15-24 hours at 5 gpm/sq ft have been maintained when operating to a terminal head loss of 15 feet of water.

Suspended solids concentrations of 200 mg/l or more will lead to uneconomically short filter runs. Figure A-17 illustrates the effects of influent solids on rate of headloss buildup.

Estimating the filtration efficiency of effluents from biological secondary treatment processes is difficult due to variations in effluent quality from those processes. However, the following prediction of filter effluent qualities are presented as a general guide to suspended solids concentrations which might be expected from various secondary processes: high rate trickling filter, 10-20 mg/l; two-stage trickling filter, 6-15 mg/l; contact stabilization, 6-15 mg/l; conventional activated sludge, 3-10 mg/l; and extended aeration - complete mix activated sludge, 1-5 mg/l.[4] The addition of chemical filter aids will substantially increase the efficiency of suspended solids removal.

As previously mentioned, high filter influent suspended solids concentrations affect filtration performance, with concentrations in excess of 200 mg/l causing uneconomically short filter runs. High pH (greater than 9), as from an upstream chemical treatment step, will cause deposition of carbonates on the filter media and mechanical appurtenances. Certain portions of the filter such as piping and valves should be protected from extreme cold temperatures.

The backwash operation is also sensitive to certain parameters, with water temperature and air in backwash water being the most significant. The backwash rate required to achieve a given expansion depends upon the water temperature. A rise in water temperature from 10°-20°C will require an increase in backwash rate of about 30 percent to maintain the same expansion.[4] A backwash flow indicator is necessary to insure that desired backwash rate is constantly maintained. Air, introduced with the backwash water which may cause blowing out and overturning of filter media, can be eliminated with proper design and operation.

Filtration, like all processes which require pumping or electrical power equipment, requires a constant source of power supply for continuous operation. An auxiliary power supply will insure continuous operation. The EPA now requires emergency standby power generation units for newly constructed treatment facilities; thus, continuous operation will be assured.

Design Assumptions

Performance data from the South Lake Tahoe treatment plant was utilized to establish the sizing and cost parameters for this report. Based on that experience, a design filter rate of 5 gpm/sq ft and backwash rate of 15 gpm/sq ft were assumed. It was assumed that mixed-media filtration operated in a downflow

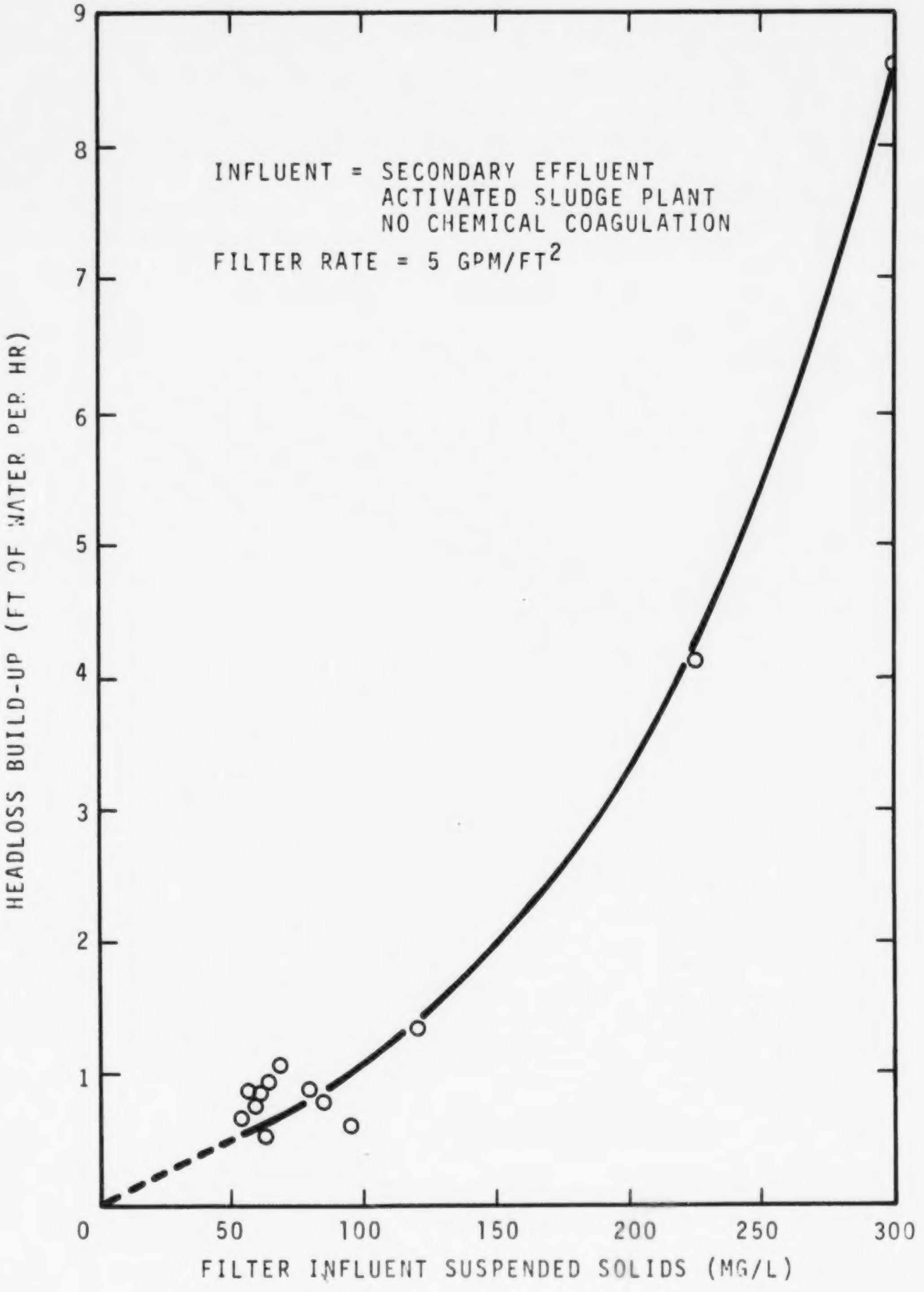


FIGURE A-17. EFFECT OF FILTER INFLUENT (ACTIVATED SLUDGE EFFLUENT) SUSPENDED SOLIDS ON HEADLOSS BUILDUP FOR MIXED-MEDIA FILTER[4] mode would be incorporated into all treatment strategies where filtration is specified. Reliable operation of upstream treatment units was also assumed. Provisions for surge control via equalization or ballast ponds just prior to filtration were assumed in order to provide constant head and flow to the filters. Backwash is initiated by high headloss, high turbidity, or manually. The land requirement for this process was assumed to include area for the ballast ponds.

COAGULATION-FLOCCULATION

Process Description

The removal of suspended matter from wastewater is normally accomplished by sedimentation and/or filtration processes. In order for these processes to function in a practical manner it is necessary that the particles of suspended matter be of sufficient size to either settle in a relatively short period of time or be removed by entrapment in the void spaces of a filter bed. However, because a significant fraction of the suspended matter in wastewater often consists of particles too small for effective settling or filtration, the aggregation or precipitation by coagulation and flocculation of these particles into larger more readily settleable or filterable aggregates is common practice.

The function of chemical coagulation-flocculation of wastewater is the removal of suspended solids by distabilization of colloids and removal of soluble inorganic compounds, such as phosphorus, by chemical precipitation or adsorption on chemical floc.[4] Coagulation involves the reduction of surface charges of colloidal particles and the formation of complex hydrous oxides or precipitates. Coagulation is essentially instantaneous in that the only time required is that necessary for dispersing the chemical coagulants throughout the liquid. Flocculation involves the bonding together of the coagulated particles to form settleable or filterable solids by agglomeration. This agglomeration is hastened by stirring the water to increase the collision of coagulated particles. Unlike coagulation, flocculation requires definite time intervals to be accomplished.[4]

Coagulation in wastewater serves a dual purpose. Not only can removal of suspended solids (and BOD) be enhanced as was the original intention in early wastewater treatment, but also effective phosphorus removal can be obtained. Presently, many treatment facilities use coagulation processes primarily for phosphorus removal with effective suspended solids removal an added bonus.

Chemicals commonly used in wastewater coagulation are aluminum sulfate (alum), lime, or iron salts such as ferric chloride. Alum and lime both offer the potential of coagulant recovery while no practical means of recovery of iron salts has yet been demonstrated.

The colloidal suspensions found in wastewater consist of very fine particles which carry an electric charge on their surface. The particles are repelled from one another by this charge which causes them to remain in suspension. The stability of colloidal suspensions in water is based on the ability of the particles to retain their surface charge. This charge can be overcome by addition of the coagulants mentioned above to destabilize the suspension allowing particles to aggregate (flocculate) and form larger particles (floc) that settle easily. Addition of long-chained high molecular weight organic molecules (polymers) can aid in flocculation by a "bridging" mechanism between floc particles.

When lime is added to wastewater, it reacts with the bicarbonate alkalinity of wastewater to form calcium carbonate and also reacts with orthophosphates present in wastewater to precipitate hydroxyapatite as shown in the following equations:

$$Ca(OH)_2 + Ca(HCO_3)_2 \rightarrow 2CaCO_3 + 2H_2O$$

$$5Ca + 4OH + 3HPO_4 \rightarrow Ca_5OH(PO_4)_3 + 3H_2)$$

Lime treatment normally includes flocculation to aid in removal of phosphorus, suspended solids, and BOD present in wastewater. The floc is settled and removed as a sludge. If lime clarification is accomplished in the primary settler, the high pH of the resultant effluent can be reduced by addition of CO_2 in an aeration basin to form $CaCO_3$. The $CaCO_3$ also aids in floc settling.

The removal of phosphates by aluminum salts such as aluminum sulfate (alum) is accomplished by a precipitation-coagulation-flocculation sequence much the same as with lime treatment. Removal of the resulting suspended particles is accomplished by either conventional sedimentation or some form of filtration. When alum is added to wastewater in the presence of alkalinity, the following hydrolyzing reaction occurs:

$$\underset{\text{(alum)}}{Al_2(SO_4)_3} + 6HCO_3^- \rightarrow 2Al(OH)_3 \downarrow + 3SO_4^{-2} + 6CO_2$$

The resulting aluminum hydroxide complex is a gelatinous, bulky floc which catches and adsorbs colloidal particles on the growing floc providing clarification.

If the water to be treated is of low alkalinity, a poor floc will be formed due to solubilizing of the aluminum hydroxide. It may be necessary to add hydroxide in the form of lime or some other base to raise the pH above about 6 to assure that the floc remains insoluble.

In the presence of phosphates, the following reaction also occurs:

$$Al_2(SO_4)_3 + 2PO_4^{-3} \rightarrow 2AlPO_4 + 3SO_4^{-2}$$

The two alum reactions compete for the aluminum ions. At pH values above 6 to 6.3, the removal mechanism of phosphate is either by incorporation in a complex with aluminum or by adsorption on aluminum hydroxide floc.[4] To obtain removal of phosphates by coagulation and precipitation, to the limit of the solubility of aluminum phosphate, it is required that an amount of aluminum ion be added in excess of the stoichiometric amount. Hence, in practice, aluminum to phosphate molar ratios of 1.2 to 2.0 must be added depending on the final phosphorus concentration desired and the chemical characteristics of the particular wastewater involved.[196]

In general, coagulation reactions vary significantly with changes in pH, so pH adjustment of the influent may be required to achieve optimum conditions. Also chemically treated wastewater may require pH adjustment with additional chemical before effluent discharge, to meet water quality standards.

Anions present in wastewater extend the optimum pH range for coagulation to the acid side to an extent dependent upon their valency. Thus monovalent anions such as chloride and nitrate have relatively little effect while sulfate and phosphate (from detergents) cause marked shifts in optimum pH.[195]

Coagulation processes to be followed by filtration differ in that it is desirable to form smaller particles that interact with the filter media to reduce the pore space through which the filtrate must pass. This is as opposed to coagulation for sedimentation where it is desirable to form large particles for faster settling.[4]

Selection of coagulants, coagulant aids and chemical dose are based on experience and bench scale jar tests using samples of the wastewater and various chemicals and doses to determine that combination giving the best results. Understanding of coagulation theory does provide a basis for limiting the number of trials required to find a workable combination.

Coagulating chemicals must be added to the wastewater, mixed, then gently stirred for flocculation. Detention times, amount of chemical, and the type and amount of mixing vary with the chemical used and the character of the wastewater. Difficulties are encountered in coagulation and flocculation when wastewater temperature approaches 0°C. The settling characteristics of the floc become poor, and there is an increased tendency of floc to penetrate any filtering media, suggesting that floc strength has decreased.[195] It has been observed that the optimum pH value is decreased by decreases in temperature and that this shift becomes more important with smaller coagulant doses.

Mixing of the chemicals upon addition to the wastewater may be accomplished hydraulically through a pump or a pipeline or may involve a tank equipped with a mechanical stirring device. Stirrers consisting of a propeller agitator on an electric motor driven shaft are common.

Chemicals may be added to the wastewater manually or mechanically. Chemical feeding equipment is available that feeds dry chemicals on a volumetric basis. Dry feeders use variable speed drives to achieve different feed rates.

Proportioning pumps are used to feed chemicals from pre-mixed stock solutions. This method is most common when organic polymers, alum or iron coagulants are used. The pumps feature variable speed drives and non-corrosive parts.

Chemical feeding and rapid mixing is followed by a period of gentle stirring to promote flocculation lasting from 15 to 60 minutes depending on the characteristics of the chemical added and the wastewater.[4] In flocculation, vertical or horizontal paddle stirring devices generally provide gentle mixing to maximize contact between the coagulated chemicals and suspended particles in the wastewater. Peripheral velocities of the stirrers are low (30-60 cm/sec) to avoid agitation sufficient to break up the flocculated particles. Air diffusion may also be used for stirring.[31]

Chemicals are usually added in proportion to flow requiring flow metering and indicating equipment that may be arranged to automatically regulate chemical dose according to preset levels. Automatic control and mechanical mixing causes the process to be vulnerable to power failure.

Flocculated wastewater flows to a sedimentation basin where the particles are allowed to settle out and are removed as sludge. Alternatively, the wastewater may flow directly to a filter system. Sufficient care must be taken to assure velocity gradients during transport are low enough to prevent shearing of the fragile floc.

Clarifiers (sedimentation units) are available that combine the mixing and flocculating processes in a partitioned section in the center of the tank thus providing for recirculation of the flocculated suspension for variable detention and mixing time and to realize savings in tank cost. These are often called "reactor clarifiers," "sludge blanket clarifiers;" or "solids contact clarifiers."

The resulting sludge produced in the total treatment process includes the precipitated fraction from the wastewater plus that from the chemical added. Chemical recovery from the sludge is often possible but involves additional space, equipment and operation.

Skilled operation of both package and full scale plants is essential to obtain satisfactory treatment results at minimum cost. Operator time is consumed in conducting tests to determine optimum chemical types and doses required to achieve the desired treatment results. Careless operation may not result in total treatment failure but easily to chemical wasteage, thereby adding to treatment costs.

Chemical coagulation-flocculation and sedimentation can remove 80-90 percent of the total suspended matter, 50-55 percent of the total organic matter and 80-90 percent of the bacteria from raw wastewater as compared to plain sedimentation which removes 50-70 percent of the total suspended matter and 30-40 percent of the organic matter.[31]

Design Assumptions

A two stage lime treatment with a total dose of 250 mg/l, was chosen for use in the coagulation-flocculation-precipitation process. Lime will form an insoluble precipitate with phosphorus and the resulting sludge is easy to dewater when compared to other chemical sludges. Also, in a large treatment plant economical recovery of the lime is possible.

The amount of chemical sludge produced daily is a function of several variables including flow; lime dose; calcium, magnesium and phosphorus content of the wastewater; and the amount of nonvolatile suspended solids present in the influent to the chemical clarifiers. The amount of chemical sludge which must be handled in the system is, in turn, a function of daily sludge production and degree of removal of inert materials by classification and blowdown. Sludge quantities are given in each sludge option presented.

CARBON SORPTION

Process Description

Activated carbon has been utilized in numerous industrial products and processes for many years, and much of the present application technology has developed therefrom. In the last ten years, granular activated carbon treatment of wastewater has been demonstrated for both municipal and industrial applications. The process has become much more attractive for widespread use due to the development of economical regeneration methods and equipment for granular activated carbon.

There are currently two approaches for the use of granular activated carbon in wastewater treatment. The first approach is to use activated carbon in a "tertiary" treatment sequence following conventional primary and biological secondary treatment. The second approach utilizes activated carbon in a "physical-chemical" treatment (PCT) process in which raw sewage is treated with chemicals prior to carbon sorption.

The use of activated carbon in tertiary treatment systems makes maximum use of its capability to sorb certain refractory dissolved organics from wastewater by limiting its use to this function alone.

Conventional biological processes remove nearly all of those organics measured by the biochemical oxygen demand (BOD) test, or soluble BOD. However, these processes are ineffective in removing the so-called refractory organic materials as measured by the chemical oxygen demand (COD) test. Activated carbon is extremely effective at removing these refractory organics from wastewater.

Sorption is usually explained in terms of surface tension or surface energy per unit area. This tension or energy is caused by an unbalance of forces on the molecules in the surface layer of the carbon. According to the most generally accepted concepts of sorption, this surface phenomenon may be predominantly one of electrical attraction of the solute to the carbon, van der Waals attraction, or of a chemical (ionic) nature.[206] Sorption of dissolved substances from wastewater is probably primarily a result of physical attraction or van der Waals forces.

Because sorption is a surface phenomenon, the ability of activated carbon to sorb large quantities of organic molecules from solution stems from its highly porous structure, which provides a large surface area. Carbon has been activated with reported yields of some 2500 sq meters per gram of carbon, but average surface areas of granular activated carbon are around 1000 sq meters per gram of carbon.[207]

Generally, molecules of higher molecular weights are attracted more strongly by activated carbon than lower weight molecules.[208] Furthermore, activated carbon will preferentially adsorb nonpolar organic molecules from polar solvents, such as water. The forces of attraction between the carbon and the molecules to be adsorbed are greatest when the molecules are just large enough to be admitted into the pore openings.

Several inorganic, physical and environmental parameters affect sorptive characteristics of activated carbon. Decreasing pH increases the sorptive characteristics. Sorption is very poor at pH values above 9, in fact desorption may occur at high pH. Temperature has a significant effect on sorption characteristics. Increasing temperature increases the rate of sorption but not the ultimate capacity of the activated carbon.

The effect of suspended solids in wastewater applied to granular carbon has not been determined precisely. However, it is evident that any restriction of pore openings or buildup of materials within the pores might decrease the sorptive capacity and/or service life of the carbon.[4] This effect can be minimized by applying water which has been pretreated by filtration.

Particle size is generally considered to have no effect on adsorptive capacity. The external surface constitutes a small percent of the total surface area of an activated carbon particle. Reducing the particle size of a given weight of activated carbon from 1 millimeter to 10 microns (0.01 millimeter) only slightly increases the total sorptive capacity.

Headloss in the carbon contactor is an important design consideration and is influenced by the carbon particle size and the flow rate. The suspended solids concentration in the wastewater to be treated by the carbon will also affect the headloss and will thereby be a factor in selection of carbon particle size.

The flow rate and bed depth necessary for optimum performance will depend upon the rate of sorption of impurities from wastewater by the carbon. Increasing flow rates through the carbon will cause increasing headlosses.

The general range of flow rates (or hydraulic loading) is 2-10 gpm/square foot of cross sectional area. Bed depths are usually 10-30 feet.

Hydraulic headloss is then related directly to flow rate and inversely related to particle size. Figure A-18 illustrates the increasing pressure drop with increasing hydraulic loading for different sized carbons from different manufacturers, operated in a downflow mode. Because of the more favorable headloss characteristics, 8 x 30 mesh carbon is often preferred for downflow beds while 12 x 40 mesh carbon may be preferrable for upflow beds because a lower upflow velocity is required for expansion.

The headloss for a given hydraulic loading with wastewater feed must be determined by pilot testing. Since headloss development is such an important consideration in the design of a carbon bed, hydraulic loading cannot be discussed in isolation from several other design factors. If an excessive rate of headloss development (due to a high hydraulic loading) is anticipated, an upflow bed should be given consideration. The choice of gravity versus pressurized flow may also be influenced by the anticipated rate of headloss development. Very high hydraulic loadings are practical only in pressurized systems. Gravity flow in downflow beds is considered practical only at hydraulic loadings less than about 4 gpm/ft^2.

Upflow expanded beds should be considered when high headloss is expected. At low flow rates, the particles are undisturbed and the bed remains fixed. As the flow rate is increased, however, a point is reached where all particles no longer remain in contact with one another, and the carbon bed is expanded in depth. The flow rate required for initial expansion of the bed is accompanied by a sizable increase in headloss. As the flow rate is increased, there is further expansion of the bed. Flow rates required for further expansion of the bed are accompanied by lesser increases in headlosses. Figure A-19 illustrates the sharp increas in ΔP for initial bed expansion and the lower rate of increase for further expansion. Figure A-20 shows expansion of 8 x 30 and 12 x 40 mesh carbon beds at various flow rates.

It has been found that at about a 10 percent expansion of an upflow bed, suspended solids will pass through the bed. In Figure A-20 a 10 percent expansion occurs at approximately 6 gpm/ft^2 for 12 x 40 mesh carbon and at about 10 gpm/ft^2 for 8 x 30 mesh carbon.

The purpose of backwashing is to reduce the resistance to flow caused by solids that have been trapped in the bed. The rate and frequency of backwash is dependent upon the hydraulic

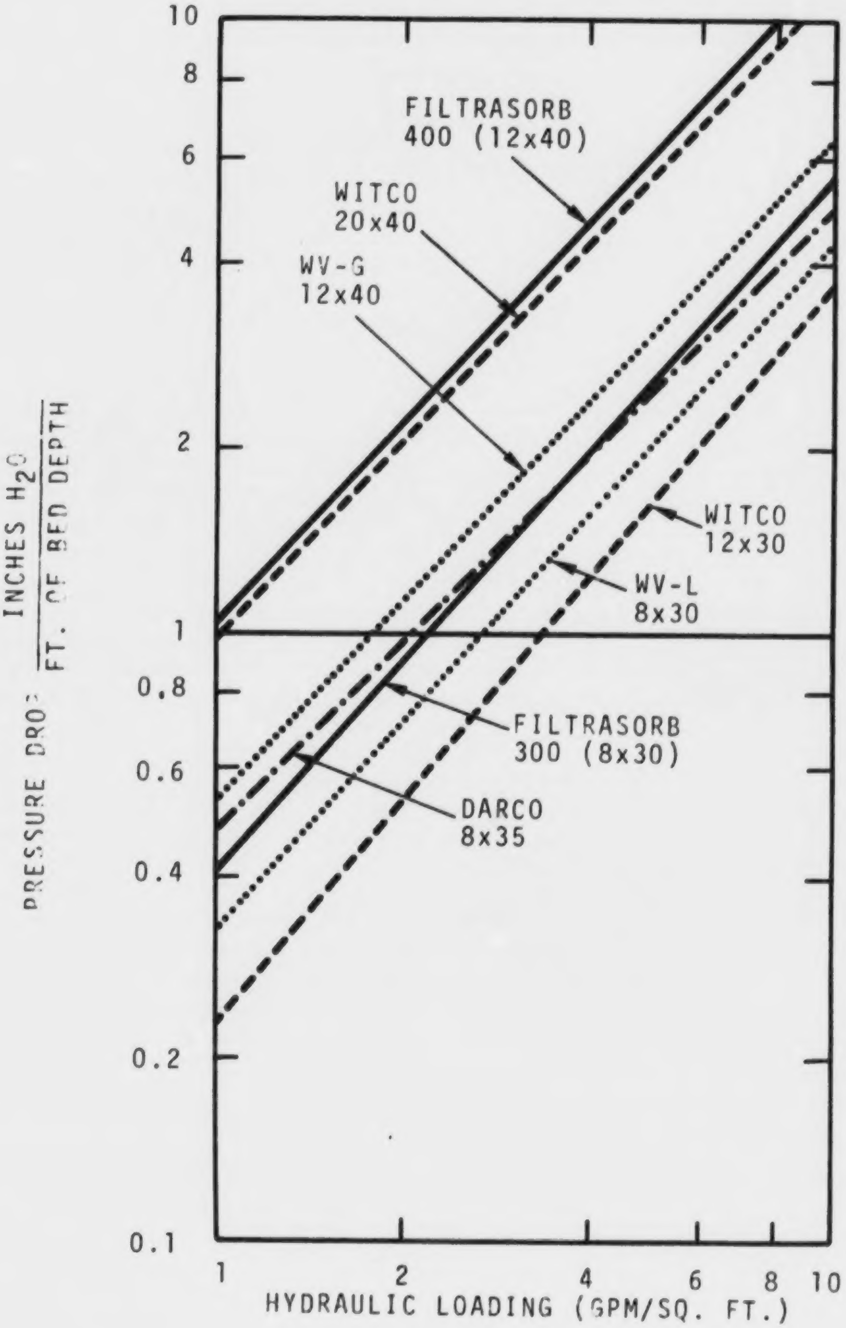


FIGURE A-18. PRESSURE DROP VERSUS HYDRAULIC LOADING IN GRANULAR ACTIVATED CARBON BEDS[206]

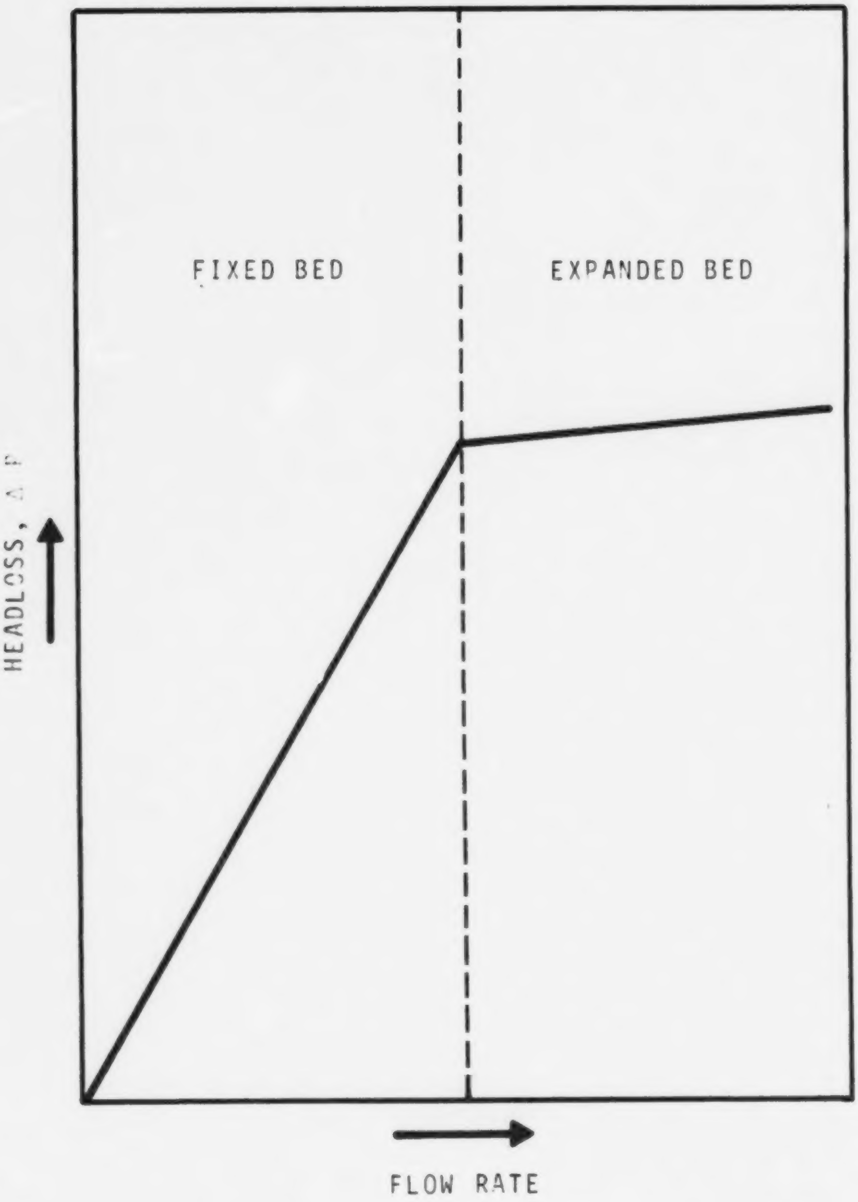


FIGURE A-19. HEADLOSS ON BED EXPANSION[206]

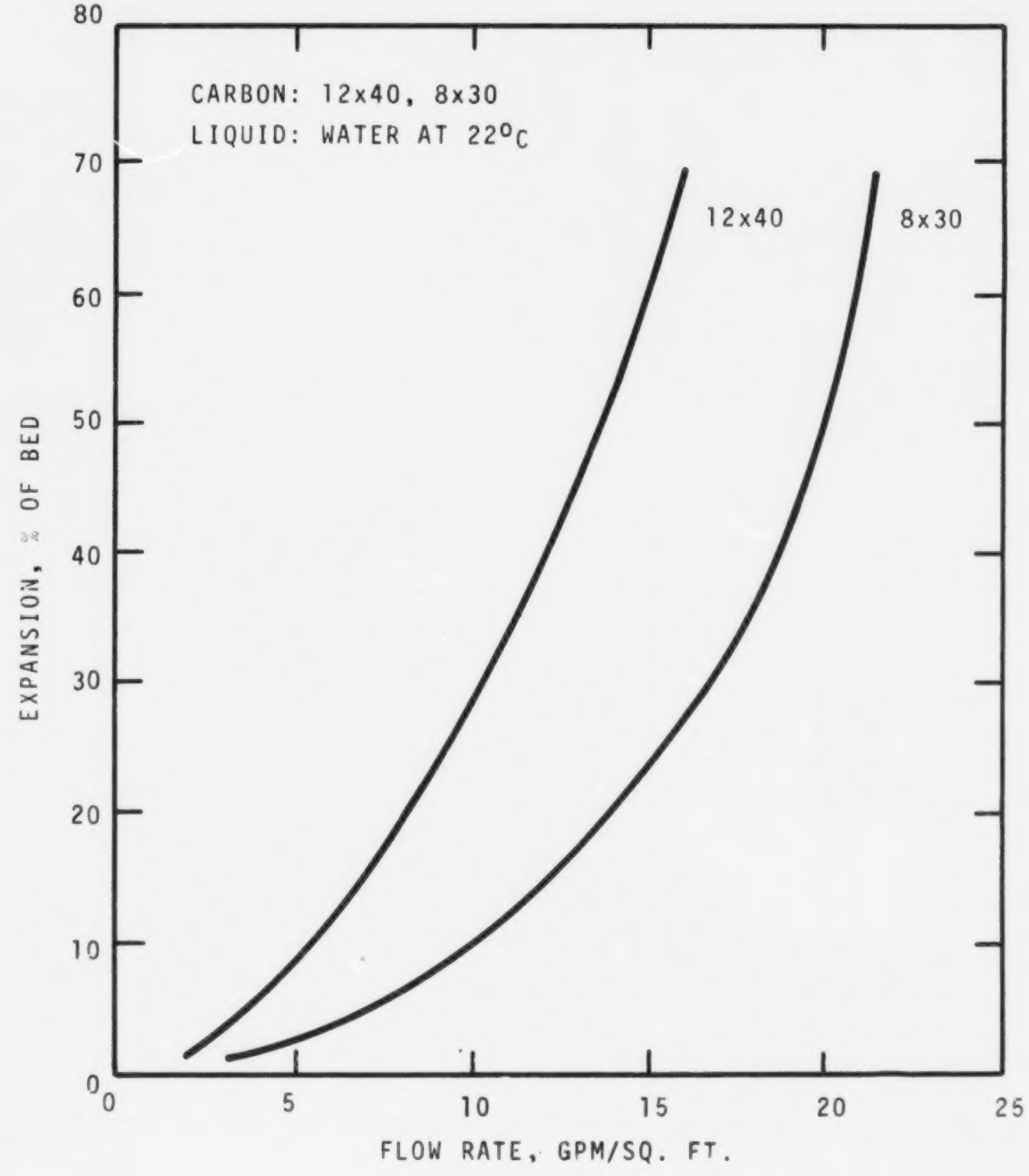


FIGURE A-20. EXPANSION OF CARBON BED AT VARIOUS FLOW RATES[4] loading, the nature and concentration of the suspended solids in the wastewater, the carbon particle size, and the method of contacting (upflow, downflow). A contactor operating at a hydraulic loading of 7 gpm/ft^2 may be backwashed daily to counteract excessive pressure drop. The same contractor operated at 3.5 gpm/ft^2, with the same suspended solids loading may require backwashing only every 2-1/2 days.

Backwash frequency may be determined by either buildup of headloss or deterioration of effluent turbidity, or initiated at regular predetermined intervals of time. It may be convenient for operational reasons to arbitrarily backwash beds at one-day intervals, for example, without regard for headloss or turbidity. The other criteria may only be of interest during periods of shock solids loading when backwash frequency exceeds once per day.

The removal of solids trapped in a packed upflow bed may require two steps: first, the bottom surface plugging may have to be relieved by temporarily operating the filter in a downflow mode, and second, the suspended solids entrapped in the middle of the bed may have to be flushed out by bed expansion.

Backwashing of packed upflow carbon contactors which are preceded by filtration merely consists of increasing upflow from the normal rate of 5 to 6 gpm/ft^2 (for 8 x 30 mesh carbon) to 10 to 12 gpm/ft^2 for 10 to 15 minutes. This can be done without taking the column out of service. A 10 percent void space in the top of contactor above the carbon is sufficient for this purpose. If the top (effluent) screens are partially plugged, the flow may be reversed (downflow) for a few minutes to clear the screen openings.

Backwashing normally requires a bed expansion of 10-50 percent. It is recommended that a backwash flow rate of 12-15 gpm/ft^2 be used with the granular carbons of either 8 x 30 mesh or 12 x 40 mesh.

Effective removal of the solids accumulated on the carbon surface in downflow contactors requires: (1) surface wash equipment utilizing rotating or stationary nozzles for directing high pressure streams of water at the surface of the bed, or (2) an air wash. A surface wash or air wash system is normally operated only during the first few minutes of a 10-15 minute backwash. When backwashing is supplemented by this scouring type of wash, the total amount of water to achieve a given degree of bed cleaning may be reduced. Also, surface wash or air wash overcomes bed plugging that may not be alleviated by normal backwash velocities. As a general rule, the total amount of backwash water required should not exceed 5 percent of the average plant flow.

Backwash water may be effectively disposed of by recirculating it into the primary sedimentation basin or elsewhere near the inlet of the wastewater treatment plant. A return flow equalization tank may be advisable in order to reduce shock hydraulic loads on the plant from waste washwater.

Washing an expanded upflow bed is a simple operation. It requires stopping the influent, lowering the liquid level in the contactor to within one foot above the top of the carbon, and directing a stream of air into the carbon bed for 5 minutes to dislodge accumulated solids. After the air scouring, the column is backwashed with water for 30 minutes and then returned to service.

Figure A-21 is a cross-section view of a typical carbon column, which may be operated in either an upflow or downflow mode. Upflow beds have an advantage over downflow beds in the efficiency of carbon use because they utilize the countercurrent mode of operation. Countercurrent operation results in near optimum utilization of carbon, or the lowest carbon dose rate. Upflow beds may be designed to allow addition of fresh carbon and withdrawal of spent carbon while the column remains in operation. Upflow packed bed columns are suitable only for low turbidity water (<2.5 JTU), and should be loaded with carbons no finer than 8 x 30 mesh because of plugging and high head loss problems. Upflow expanded beds have the advantages of being able to treat wastewater relatively high in suspended solids, and of being able to use finer carbon (which reduces the required contact time) without excessive head loss.

Downflow carbon contactors operate as a filter-contactor, accomplishing both sorption and filtration of wastewater. The dual use of carbon may result in some reduction of capital costs by eliminating filtration equipment. However, this economic gain may be offset by a loss of efficiency in both filtration and sorption. Further, it does not seem reasonable to use a high cost media (carbon) for the removal of suspended solids when a lower cost media (sand) is so successful.

In summary, activated carbon has proven itself in the removal of a wide variety of organic and inorganic materials. Commercially available granular carbons vary in sorptive characteristics and may be evaluated and compared via laboratory and pilot column tests. However, long-term plant scale demonstration is the only way to determine the full merit of a granular

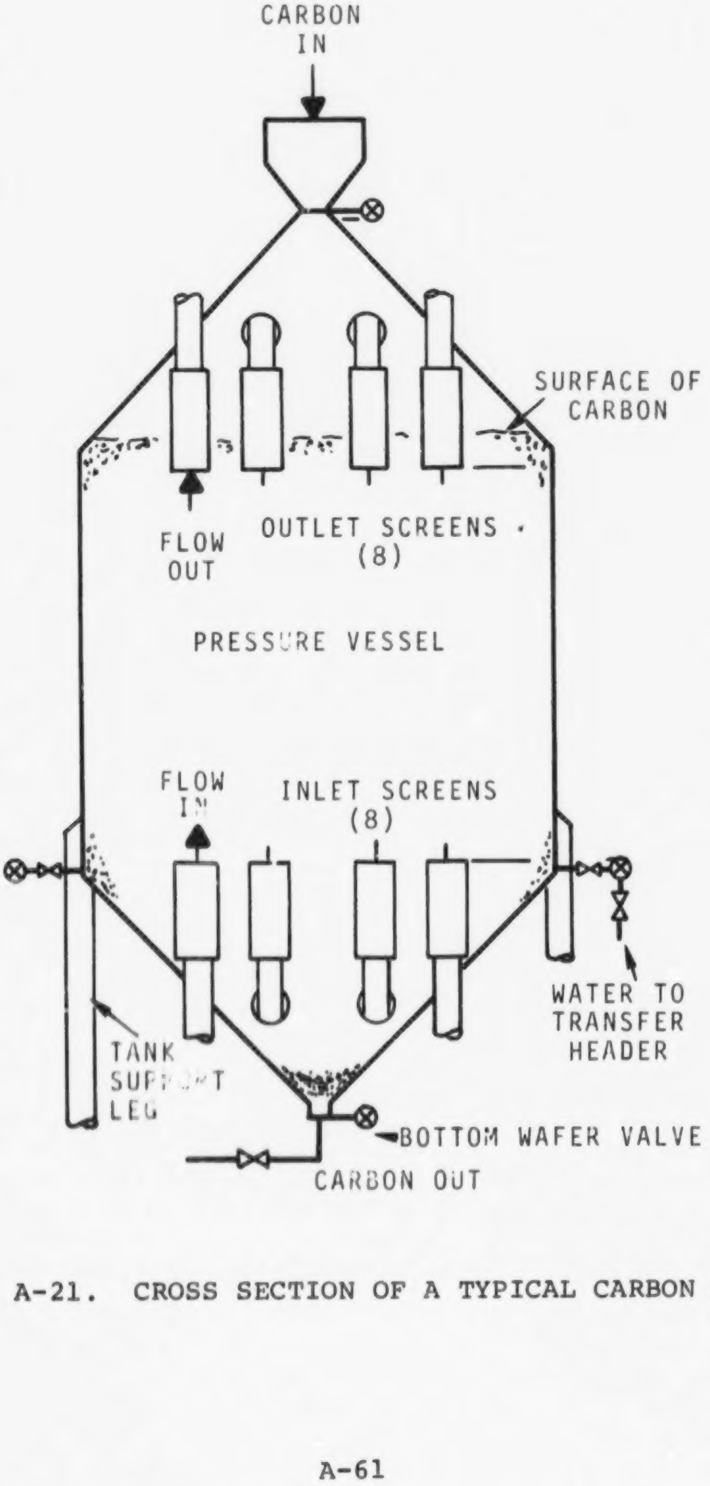

CARBON IN
SURFACE OF CARBON
FLOW OUT
OUTLET SCREENS (8)
PRESSURE VESSEL
FLOW IN
INLET SCREENS (8)
WATER TO TRANSFER HEADER
TANK SUPPORT LEG
BOTTOM WAFER VALVE
CARBON OUT

FIGURE A-21. CROSS SECTION OF A TYPICAL CARBON COLUMN[206] carbon. Unfortunately, only plant scale experience of long duration can be used to predict the durability of a carbon with respect to mechanical attrition losses. The use of granular activated carbon for wastewater treatment and its regeneration are proven reliable and successful processes.

Design Assumptions

Carbon requirements differ based on whether used as tertiary treatment or in physical-chemical treatment. Carbon requirements including regeneration for tertiary treatment were assumed at 250 lbs per million gallons and for PCT were assumed at 500 lbs per million gallons. Carbon columns were upflow packed bed pressure units filled with 8 x 30 mesh carbon. Hydraulic loading rate was assumed at 5 gpm/ft^2 and a contact time of 30 minutes. Backwash rate was assumed at 15 gpm/ft^2, and backwash was on a daily basis to minimize biological growths with resultant H_2S odor problems.

NITRIFICATION/DENITRIFICATION

Process Description

Nitrogenous compounds in raw sewage may be oxidized to nitrates by maintaining a suitable aerobic environment in a biological treatment system. The nitrates thus formed may then be reduced to nitrogen gas in a separate biological treatment system operated under anaerobic conditions. The oxidation step is referred to as nitrification and the reduction step as denitrification. The apparent simplicity of the structures needed for the biological nitrification-denitrification process and the fact that the discharge of the waste nitrogen gas presents no environmental problems has led to many studies of this process.[16,151-157] The biological nitrification-denitrification process is currently one of the leading candidates for nitrogen removal from municipal wastes.

In settled domestic sewage, nitrogen may be approximately divided into the following categories: 55-60 percent NH_3 nitrogen, 40-45 percent organic nitrogen, and 0-5 percent NO_2^- and NO_3^- nitrogen. In the course of biological treatment the organic nitrogen compounds are degraded and the proportion in the final effluent is generally less than 20 percent. Conventional activated sludge plants in the United States are designed to avoid nitrification; therefore, most of the nitrogen in the effluent from these plants appears as ammonia.

The complete oxidation of nitrogenous compounds to nitrate in the nitrification step is a prerequisite for efficient nitrogen removal in the denitrification step.

Nitrification is performed by chemoautotrophic bacteria which use CO_2 as a source of carbon for cell material and obtain energy for the process by oxidizing inorganic substrates. Two groups of the chemoautotrophs are distinguished, each responsible for a specific phase of the nitrification process. The first group generally represented by Nitrosomonas can oxidize ammonia to nitrite:

$$NH_4 + 1.5\ O_2 \rightarrow NO_2^- + 2\ H^+ + H_2O$$

The second group generally represented by Nitrobacter is capable of oxidizing nitrite to nitrate:

$$NO_2 + 0.5\ O_2 \rightarrow NO_3$$

These organisms are characterized by rather low multiplication rates in comparison to the heterotrophic bacterial flora which make up the bulk of an activated sludge. In addition, these chemoautotrophic bacteria are significantly affected by temperature in their growth rate[158] as illustrated in Figure A-22. Certain toxic substances (e.g., heavy metals) also have an inhibiting effect on growth rate.

The limiting factor for sustaining a sufficiently high population of nitrifying organisms in an activated sludge plant is the detention time which can be provided for the cells in the system. Since the nitrifiers are intimately mixed with all other organisms and the solids in the activated sludge, detention time of the sludge in the plant will be decisive. When the detention time is sufficient to allow buildup of a sizable population of nitrifying bacteria, nitrification will occur. Nitrification can be maintained only when the rate of growth of the nitrifying bacteria is rapid enough to replace organisms lost through sludge wasting. When they can no longer keep pace, the ability to nitrify decreases and may disappear.

It has been well established that no treatment plant, including the extended aeration type, can accomplish both BOD reduction and nitrification on a year-round basis in areas where cold winters prevail. If nitrogen removal is required, and the nitrification-dentrification process is preferred, it will be mandatory to accomplish nitrification in a process separate from that of BOD reduction. A large portion of the BOD will have to be removed before the wastewater is processed in the nitrification unit.

The effect of pH on nitrification kinetics has been investigated in the pH range of 6.0 to 10.0[158] and the optimum pH was determined to be 8.6. Figure A-23 indicates that 90 percent of the maximum nitrification rate occurs in the range of pH 7.8 to 8.9.

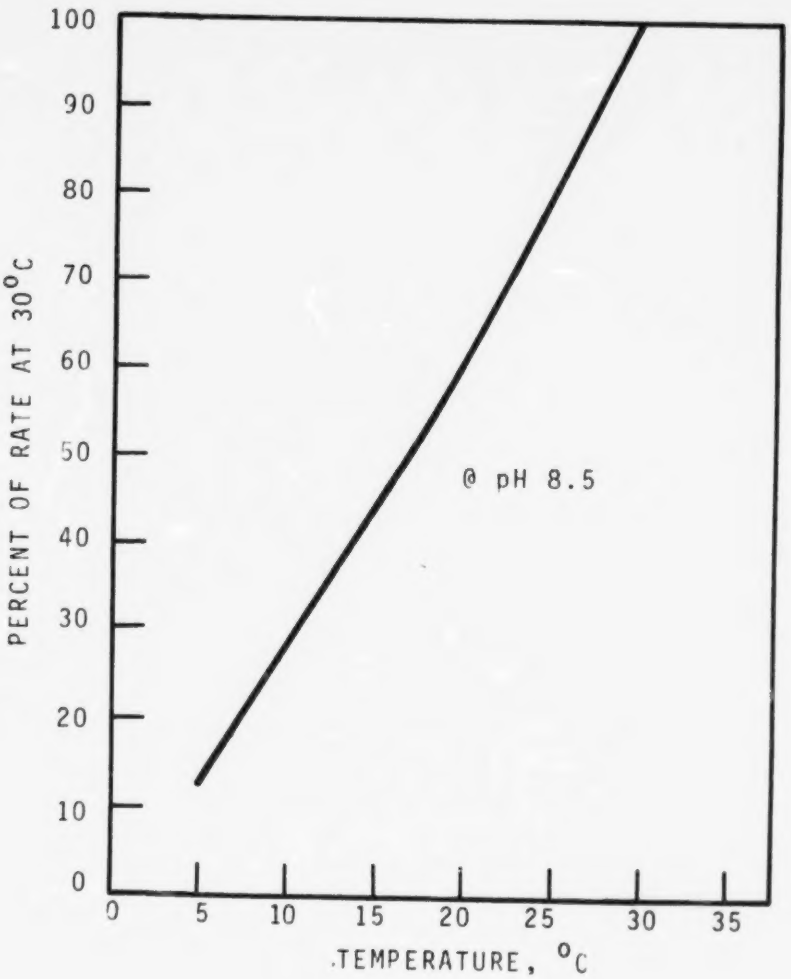


FIGURE A-22. RATE OF NITRIFICATION AT ALL TEMPERATURES COMPARED TO THE RATE OF 30°C[22]

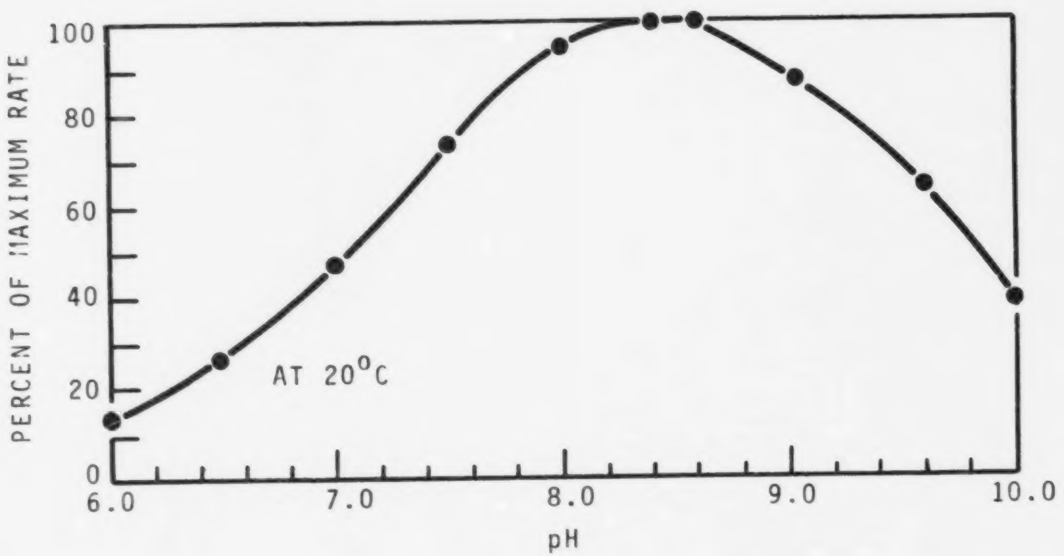


FIGURE A-23. PERCENT OF MAXIMUM RATE OF NITRIFICATION AT CONSTANT TEMPERATURE VERSUS pH[22]

Outside of the pH range 7.0 to 9.8 less than 50 percent of the optimum rate occurs. The control of pH in the nitrification process through alkali addition may be necessary since the hydrogen ion formed in the conversion of ammonia to nitrite tends to depress the pH.

Biological denitrification, which reduces nitrates to nitrogen gas, is performed by heterotrophic organisms utilizing organic sources of carbon for energy and growth in an anaerobic environment. Denitrifiers require organic carbon for their metabolic activities. Since the organic carbon content of nitrified effluent is insufficient for optimum growth of denitrifying organisms, an external source of carbon is usually added to the denitrification reactor. Several early investigators added raw sewage to the denitrification reactor, but this has the limitation of adding unoxidized nitrogen compounds and additional BOD to the final effluent. Most recent investigators have used methanol as the supplementary source of carbon because of its low cost and the ease of oxidation.

The overall denitrification step involves the following reaction:

$$6\ NO_3 + 5\ CH_3OH = 3\ N_2 + 5\ CO_2 + 7\ H_2O + 6\ OH^-$$

A suggested ratio of four parts of methanol to one part of nitrate-nitrogen has been recommended as a design guideline.[50,159]

The major difficulty expected in the operation of a biological nitrification-dentrification plant is the ammonia oxidation step. As noted previously the nitrification process is sensitive to temperature and inhibiting substances. Experiences at the Blue Plains pilot plant in Washington, D. C., illustrate some of the problems.[17] In summer and fall, nitrification continuously oxidized the ammonia nitrogen to less than one mg/l. However, in the fall, upsets in the biological processes seriously reduced nitrification. Recovery of nitrification after the upset was retarded by lower winter temperatures and a wastewater pH of 7 which is below the optimum value of 8.5 for nitrification. Although there were intermittent periods where the nitrification-denitrification units did reduce both ammonia and nitrate concentrations to less than one mg/l in cold weather, this result was not obtained consistently and reliably.

Temperature is also a controlling parameter in the denitrification phase. Increased temperature improves the rate of conversion of nitrate to nitrogen gas in the presence of methanol. Figure A-24 reflects this rate increase with increasing temperature. Furthermore, extremely low temperatures will upset the denitrification process.

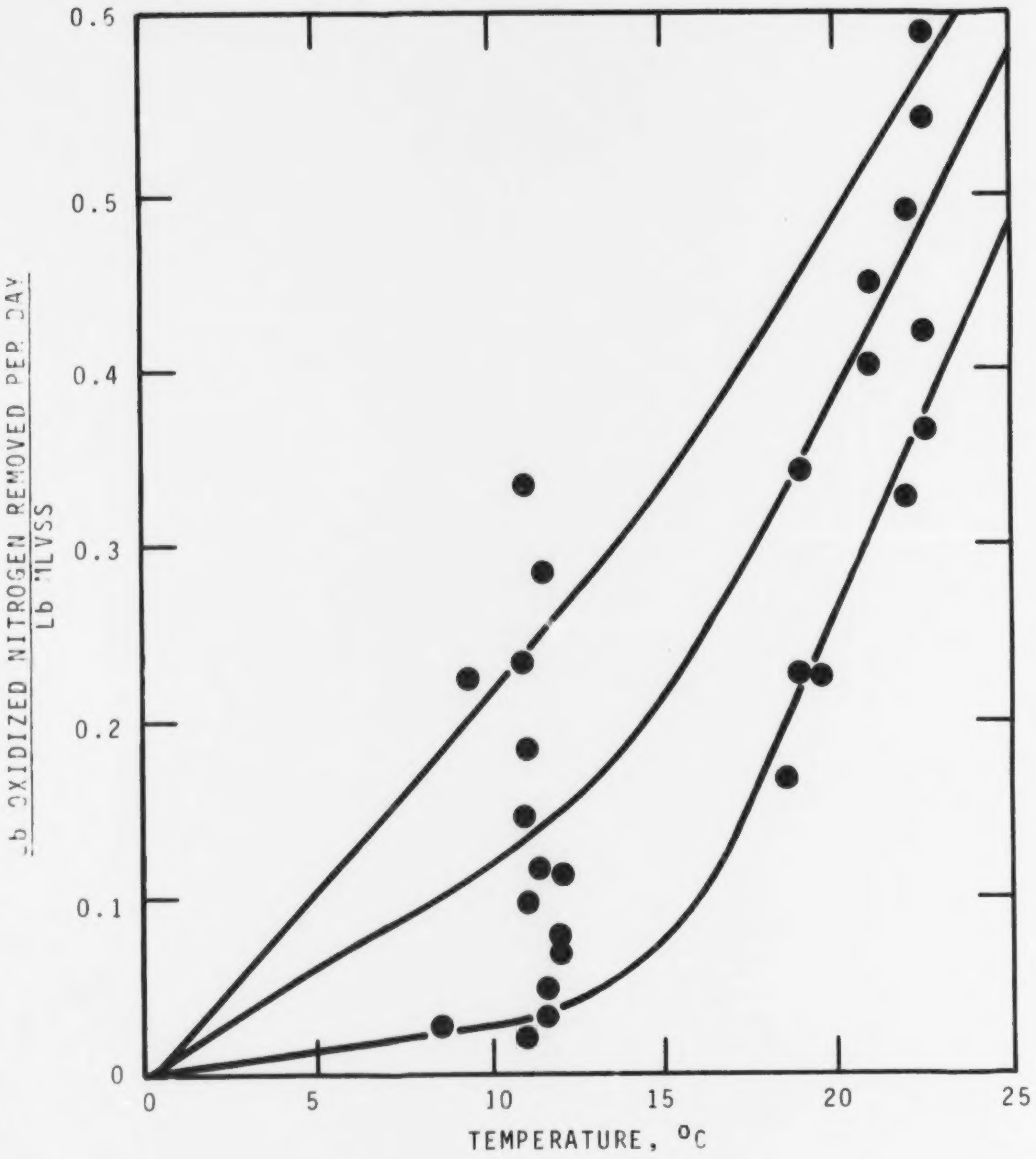


FIGURE A-24. DENITRIFICATION RATE VERSUS TEMPERATURE[47]

Problems with inhibiting substances have also been reported.[47,157] It has been suggested that means to isolate some of the nitrifying sludge be included in the process facilities so that toxic slugs do not destroy all of the nitrifying flora.

The control of methanol addition to the denitrification reactor is not a precise science. If too little methanol is added, the process will suffer a loss in efficiency. If too much methanol is added, it will escape in the plant effluent and create an oxygen demand in the receiving water.

Land area requirements for biological nitrification-denitrification are much greater than for conventional secondary treatment which is a serious disadvantage in many areas where building space at established treatment plants is limited.

Power failures can cause severe disruption to the nitrification-denitrification system's efficiency due to the numerous pumps and blowers involved. Present EPA standards require emergency standby power supplies for all new wastewater treatment facilities. This requirement should assist in preventing treatment plant upsets.

Nitrogen Removal by Suspended Growth Reactors

Denitrification can be accomplished in an activated sludge system operated under anaerobic conditions. The denitrification basin is commonly referred to as a suspended growth reactor. The contents of the reactor are mixed with underwater mixers comparable to those used in flocculation tanks in water treatment plants. The energy must be sufficient to keep the sludge in suspension but controlled to prevent pickup of atmospheric oxygen as much as possible.

Several types of nitrification-denitrification systems have been proposed. One such system is the three sludge system for BOD removal, nitrification and denitrification which employs suspended growth reactors for denitrification.[16,47,155,156] This system allows management of the separate biological transformations which are necessary for successful denitrification. A high rate activated sludge system removes the bulk of the carbonaceous material in the first stage as shown in Figure A-25. The first stage permits a high rate of sludge wasting and protects the subsequent nitrification stage from toxic chemicals. Heavy metals, cyanides, thiocyanates, and toxic organic chemicals will be either sorbed or biologically degraded before they reach the nitrification stage. Since this is a staged system there can be no direct short circuiting of materials from the influent to the effluent. Temperature effects on the enriched culture of the nitrification stage are not as extreme as with a single sludge system which contains only a marginal population of nitrifying organisms.

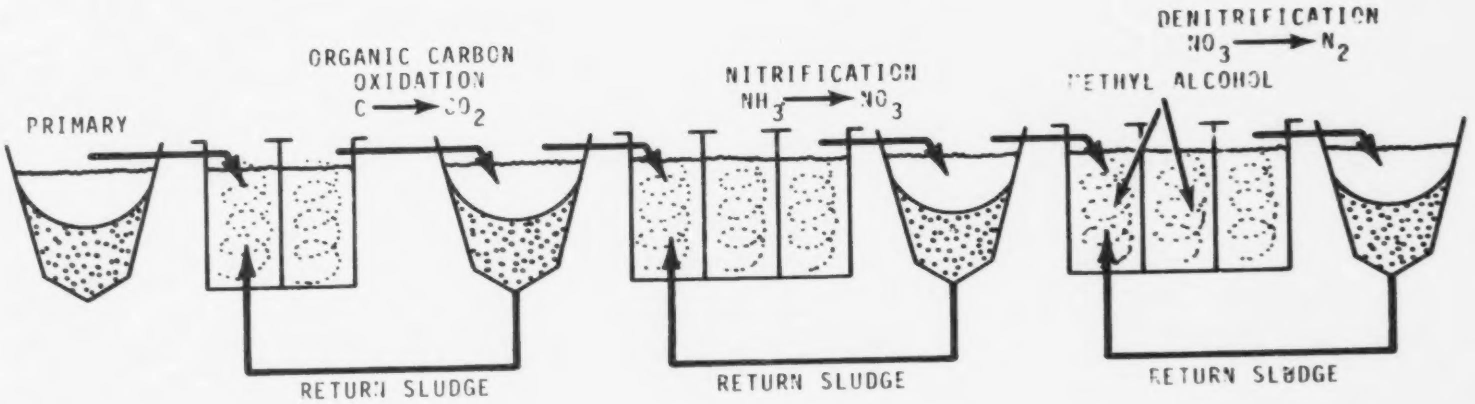

PRIMARY
ORGANIC CARBON
OXIDATION
$C \rightarrow CO_2$
RETURN SLUDGE
NITRIFICATION
$NH_3 \rightarrow NO_3$
RETURN SLUDGE
DENITRIFICATION
$NO_3 \rightarrow N_2$
METHYL ALCOHOL
RETURN SLUDGE

FIGURE A-25. THREE SLUDGE SYSTEM FOR NITROGEN REMOVAL[145]

Once controlled nitrification has been established, the biological denitrification process can be optimized. The nitrified effluent flows to a mixed anaerobic reactor where methanol is added in proportion to the nitrate-nitrogen concentration. The organisms in this stage use the oxygen component of the nitrate radical to oxidize the organic carbon of the methyl alcohol. The end products of this metabolism are elemental inert nitrogen gas and carbon dioxide which are liberated to the atmosphere.

Nitrogen release tanks are provided to remove supersaturated nitrogen gas to avoid rising sludge problems in the sedimentation basins and to provide an additional aeration period for removal of excess methanol. The tanks will also provide for mixing of alum or ferric chloride added for removal of remaining phosphate. The effluent from the denitrification system will be filtered through multimedia filters and chlorinated prior to discharge.

Another wastewater treatment plant design, (ATTF), which differs from the three sludge system in that the first stage biological oxidation process is eliminated, is shown in Figure A-26.[160] Raw sewage is treated with lime and polymer or ferric chloride for clarification and BOD removal. Lime treatment of the raw sewage has been reported to increase the BOD removal from 37-46 percent to 67-74 percent. Lime clarification in the primary treatment stage removes sufficient BOD to permit both oxidation of residual carbonaceous matter and ammonia in the secondary stage. In this way, the longer sludge ages required for year around nitrification can be attained without separating the carbonaceous oxidation and nitrification stages as in the three sludge system. In addition to phosphate removal, lime clarification also provides for heavy metal removal to protect the nitrifying organisms.

After primary clarification, the liquid is passed to the oxidation-nitrification tanks directly without an intervening recarbonation stage. External CO_2 is added by vaporization from liquid storage, when needed, to the first bay of the oxidation-nitrification tanks. However, the main source of CO_2 is not the external supply but rather the CO_2 generated in the process.

Nitrogen Removal by Column Reactors

Columnar nitrate reduction represents an alternative denitrification system to the suspended growth reactors. In a packed column the cell residence time of the surface bound slime is much greater than the hydraulic detention time. This combined with a large contact surface and short diffusion distances afforded by small media such as sand, provides an efficient system for rapid denitrification of an applied feed. Column denitrification reactors have been investigated for use on municipal wastewater[145,154] and on irrigation return flows.[161]

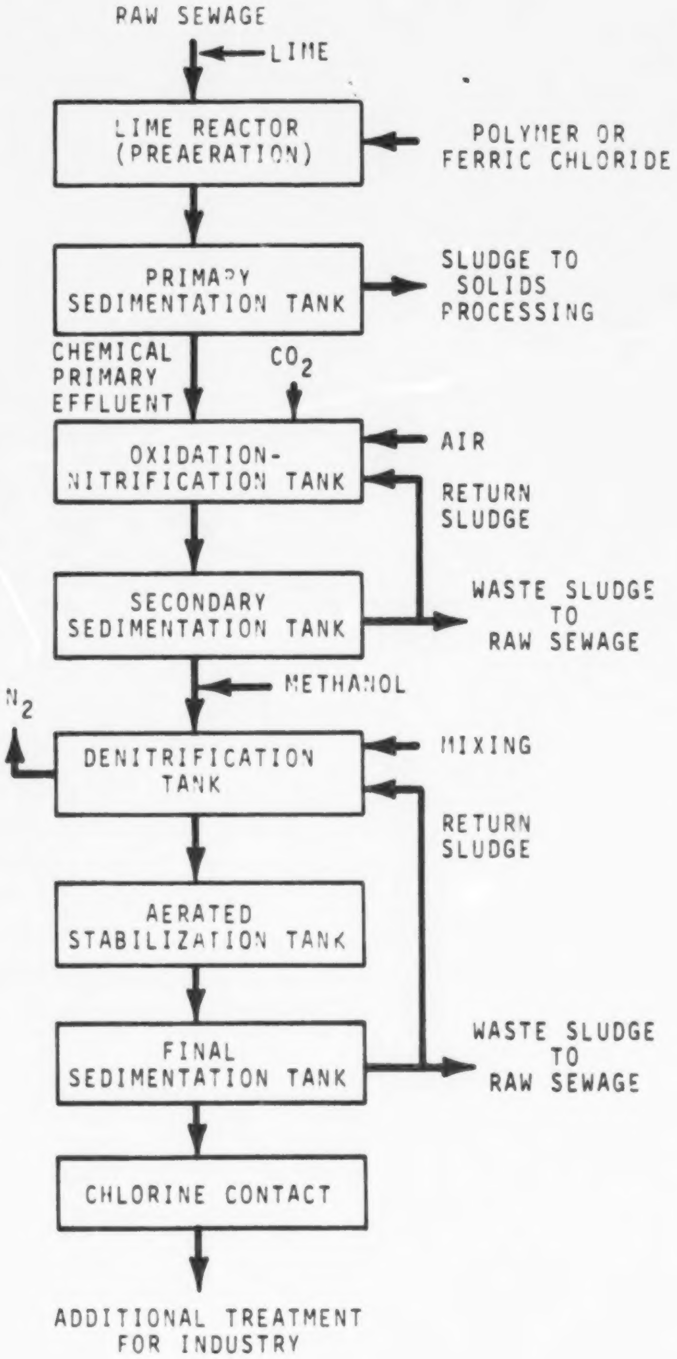

RAW SEWAGE
LIME
LIME REACTOR (PREAERATION)
POLYMER OR FERRIC CHLORIDE
PRIMARY SEDIMENTATION TANK
SLUDGE TO SOLIDS PROCESSING
CHEMICAL PRIMARY EFFLUENT
CO2
OXIDATION-NITRIFICATION TANK
AIR
RETURN SLUDGE
SECONDARY SEDIMENTATION TANK
WASTE SLUDGE TO RAW SEWAGE
METHANOL
N2
DENITRIFICATION TANK
MIXING
RETURN SLUDGE
AERATED STABILIZATION TANK
FINAL SEDIMENTATION TANK
WASTE SLUDGE TO RAW SEWAGE
CHLORINE CONTACT
ADDITIONAL TREATMENT FOR INDUSTRY

FIGURE A-26. ATTF PROCESS FLOW DIAGRAM[160]

Pilot plant studies at Pomona, California disclosed that denitrification was occurring on activated carbon columns receiving nitrified effluent.[154] The denitrification on the carbon columns was enhanced by the addition of methanol to the feed. Backwashing of the carbon columns to remove filtered solids and denitrifying organisms was accomplished without interfering with the denitrification capacity of the columns.

Haug and McCarty[162] have conducted laboratory studies using column reactors (submerged filters) for nitrifying synthetic secondary effluent. The submerged filter consists of a bed of porous media through which the wastewater passes in an upward direction. Nitrifying bacteria grow on the surfaces of the porous media and long detention times are possible. Long detention times are sometimes difficult to achieve in an activated sludge process or trickling filter, a problem that becomes increasingly difficult as the temperature decreases. The submerged filter captures almost all of the produced biological solids so that long detention times can be maintained. It also provides strict control of the hydraulic detention time. These characteristics are reported to permit nitrification at very low temperatures and under conditions of variable loading.

The submerged filter requires oxygenation of the waste with pure oxygen due to the high oxygen requirement for nitrification. Nitrification was found to be stable at temperatures as low as 1°C. With an influent concentration of 20 mg/l ammonia nitrogen, oxidation was 90 percent complete with detention times of 30 minutes at 5°C. Equivalent performance was observed with recycle using preoxygenation of waste and with bubble oxygenation in the filter.

The submerged filter is in the early stages of development and insufficient data are available for design purposes.

General Assumptions

The present study was based upon the use of the three sludge system composed of a high rate activated sludge unit (approxmate detention time of 2 hours), an aerated nitrification chamber (detention time on the order of 3 hours) and a suspended growth reactor for denitrification (detention time ranging between 50-100 minutes) with simultaneous addition of methanol. Methanol addition was based upon a rate of 4.0 mg methanol per mg of nitrate nitrogen.

The flow rates involved in the design of the system were based upon average daily flow. A volumetric loading to the high rate activated sludge stage of 100 lb BOD/1000 ft^3 was assumed to apply. Finally, diffused air aeration was assumed.

SELECTIVE ION EXCHANGE REMOVAL OF AMMONIA-NITROGEN

Process Description

The removal of ammonia-nitrogen from wastewater is required in some areas to protect aquatic life from the toxic effects of ammonia and/or to prevent excessive algal growths resulting from fertilization of the receiving water by the ammonia or nutrient nitrogen. Ammonia is the predominant nitrogen species in raw sewage or non-nitrified secondary effluents. The ammonia exists in these wastewaters essentially as ammonium cation (NH_4^+) and is therefore amenable to removal by cation exchange. This process functions by replacing the NH_4^+ ion in the wastewater with a more environmentally acceptable ion such as Na^+ or Ca^{++}. Columns of granular ammonium selective zeolite are normally employed to remove the NH_4^+ ions from the wastewater by percolating the wastewater through the granules of zeolite. Sodium and calcium ions are held by electrostatic charges within the porous structure of the zeolite granules. The Na^+ and Ca^{++} ions are released by the zeolite in exchange for NH_4^+ ions which are preferred by the zeolite. The ammonium selective zeolite (e.g., clinoptilolite) employed in this process is therefore capable of concentrating the ammonium ions in the relatively small volume of the zeolite column by contacting large volumes of wastewater.

Use of the selective ion exchange process for ammonia removal avoids the problems normally associated with the disposal of spent regenerant brine solutions. The zeolite can be effectively regenerated with lime solutions or slurries or with brine (NaCl) solutions. These spent regenerant solutions, which have a high pollution potential, are not discharged to receiving streams but are instead renovated for reuse by one of two methods: (1) air stripping to remove the ammonia, or (2) electrolytic breakpoint chlorination to convert the ammonia to environmentally acceptable nitrogen gas.

Natural zeolite, clinoptilolite, was selected for process use on the basis of its good ammonium ion selectivity and its potential low cost. Clinoptilolite is available in several large natural deposits in the Western United States. A comparison of Hector Clinoptilolite and a strong acid ion exchange resin, Amberlite IR-120^R, shows that the resin prefers calcium ions to ammonium ions whereas the opposite is true for clinoptilolite. The clinoptilolite can, therefore, be effectively regenerated with lime solutions containing calcium ions.

The clinoptilolite in the calcium form is capable of exchanging a significant portion of its Ca^{+2} ions for ammonium ions whereas a conventional ion exchange resin cannot. In the regeneration cycle, lime (calcium hydroxide) provides the basicity to convert the NH_4^+ ions to NH_3 which is non-ionic and is therefore removed from the zeolite. The exchange reactions involved in loading and regeneration are as follows:

Loadings

$$Z_2^- - Ca^{+2} + 2NH_4^+ = 2Z^- - (NH_4)^+ + Ca^{+2}$$

Regeneration

$$2Z^- - (NH_4)^+ + Ca(OH)_2 = Z_2^- - Ca^{+2} + 2NH_3 + 2H_2O$$

(Z^- is a negatively charged ion exchange site)

Regeneration with lime alone was found to be a rather slow process; therefore the ionic strength of the regenerant solution was increased by the addition of salt (NaCl). The increased ionic strength of the regenerant plus the presence of sodium ion accelerates the removal of ammonia from the zeolite. Although most of the sodium chloride added to the regenerant is converted to calcium chloride by continuous recycle of the regenerant, sufficient sodium ion remains under steady state conditions to promote the elution of the ammonium ions. The sodium ion has a higher diffusion coefficient than calcium ion which is believed responsible for increasing the ammonia elution rate.[204]

Investigations have been conducted on selective ion exchange removal of ammonia-nitrogen from clarified and carbon treated secondary effluents and from clarified raw sewage. Ammonia removals ranging from 93 to 97 percent were demonstrated in these investigations.[204,205] The flow sheet for the ammonia removal process is illustrated in Figure A-27. Clarified wastewater is pumped to the ion exchange beds either singly or in series. When exhausted, the clinoptilolite beds are removed from service, drained, and regenerated with a lime-salt solution pumped upflow through the beds. The spent regenerant is then air-stripped to remove the ammonia and returned to the chemical make-up tank where lime and salt are added to prepare the regenerant for reuse. Makeup salt is added to replace that lost during the regeneration cycle. Approximately 5 percent of the bed volume of regenerant remains in the zeolite bed after draining and is lost in the bed rinse that follows the regeneration step. The selective ion exchange process concentrates the ammonia to a small volume (about 2.5 percent of the original waste volume) which can be air-stripped at a low cost even in cold weather when heated air may be required.

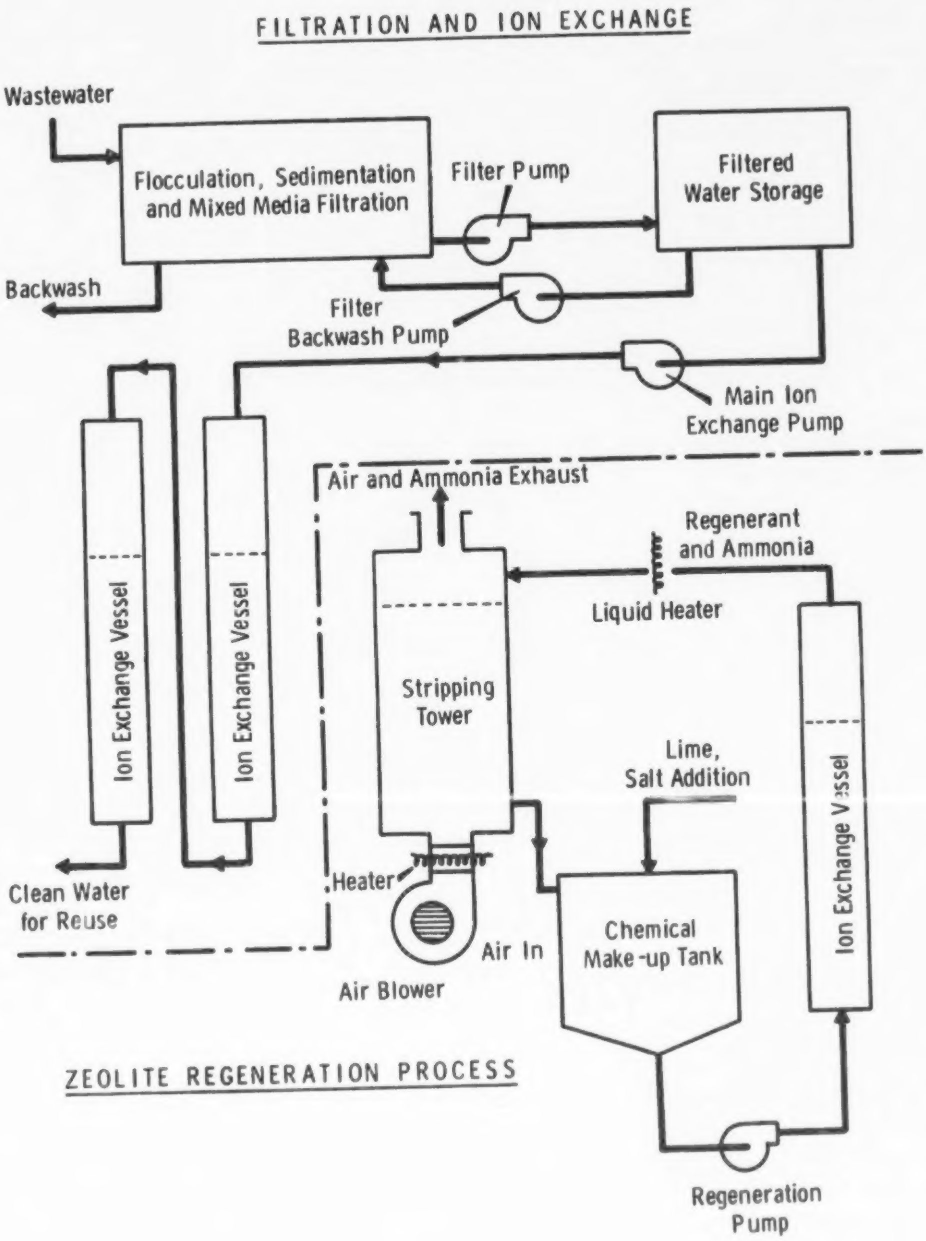

FILTRATION AND ION EXCHANGE
Wastewater
Flocculation, Sedimentation and Mixed Media Filtration
Filter Pump
Filtered Water Storage
Backwash
Filter Backwash Pump
Main Ion Exchange Pump
Ion Exchange Vessel
Ion Exchange Vessel
Clean Water for Reuse
Air and Ammonia Exhaust
Regenerant and Ammonia
Liquid Heater
Stripping Tower
Lime, Salt Addition
Ion Exchange Vessel
Heater
Air In
Air Blower
Chemical Make-up Tank
ZEOLITE REGENERATION PROCESS
Regeneration Pump

FIGURE A-27. FLOWSHEET FOR AMMONIA SELECTIVE ION EXCHANGE PROCESS[205]

A typical operational sequence can be ascertained from the plant designed (but not installed) for the South Tahoe water reclamation plant. The design included a total of 12 ion exchange beds, 9 of which would be in service and 3 in regeneration at all times. At design flow, the service cycle for a set of three beds would have to be regenerated about every eight hours. Regeneration would take place in two phases. In the first phase, regenerant from the previous regeneration with an ammonia content of 100 mg/l would be recirculated through the beds until the ammonia concentration reached a level of about 600 mg/l. Throughout the regeneration, makeup lime would be added to maintain a pH of 11. Upon completion of the phase-one regeneration, the spent regenerant would be transferred to a holding tank and thence to an air stripper for removal of the ammonia. In the second phase, freshly stripped regenerant would be circulated through the bed until the ammonia concentration reached about 100 mg/l. This regenerant would then be drained from the bed and transferred to a holding tank to be used for the first phase regeneration of the next set of beds removed from service for regeneration.

It is necessary to regenerate the beds upflow at a sufficient rate to fluidize the zeolite particles thereby removing precipitated solids [e.g., $Mg(OH)_2$] from the beds. The zeolite attrition loss per regeneration cycle has been indicated to be approximately 0.17 percent.

The problems associated with high pH regeneration [e.g., precipitation of $Mg(OH)_2$] of clinoptilolite can be avoided by using electrolytic destruction of the ammonia in place of air or stream stripping. Electrolytic treatment of the regenerants also avoids the problems of disposal of ammonia to the atmosphere or disposal of aqueous ammonia concentrates. The spent regenerant containing ammonia and chloride salts is recirculated through electrolysis cells which produce hypochlorite for breakpoint chlorination. Preliminary studies by Battelle-Northwest on electrolysis of recycled regenerant solutions containing calcium chloride and sodium chloride indicate that destruction of the ammonia can be accomplished with a power consumption of 50 watt hours per gram of ammonia-nitrogen.[205] High flow velocities through the electrolysis cells are required in addition to a low concentration of $MgCl_2$ to minimize scaling of the cathode by calcium hydroxide and calcium carbonate. Frequent acid flushing of the cells would be necessary to remove this scale when the cell resistance becomes too high for economical operation.

Cathodic scaling can be avoided by treating the spent regenerant with soda ash to precipitate the calcium as $CaCO_3$ prior to electrolytic treatment to remove ammonia. This regeneration mode utilizes a precipitation tank and a clarifer to separate the precipitated $CaCO_3$. This additional treatment of the regenerant increases the cost of the process by 1-2 cents per thousand gallons but provides the benefit of softening the wastewater to render it more acceptable for reuse in domestic water supplies and probably reduces the power requirements to about 40 watt hours/gram of ammonia-nitrogen destroyed.

The selective ion exchange process is subject to loss of ammonia removal efficiency by: (1) high pH levels (above pH 8) in the wastewater feed, (2) plugging of the zeolite bed with particulate matter in the feed, (3) bed fouling by biological growths, and (4) bed fouling by precipitated $Mg(OH)_2$ when high pH regeneration (lime solutions or slurries) is used. Control of the pH of wastewater is readily accomplished in most tertiary treatment plants by recarbonation to about pH 7 and therefore does not normally represent a problem to the selective ion exchange process. High pH conditions during the initial part of the service cycle are possible if residual lime or caustics used in the alkaline regeneration mode are not thoroughly flushed from the zeolite bed prior to introducing the feed stream.

Since the selective ion exchange process would normally be employed in an advanced waste treatment plant or a tertiary treatment plant, zeolite bed plugging by particulate matter in the feed is not a problem as this material is removed by filtration prior to either carbon sorption or ion exchange treatment. Bed fouling by biological growths would occur only in the treatment of effluent from an advanced waste treatment, physical-chemical clarification process which does not remove soluble organic matter from raw wastewater. Pilot plant results indicate that biological fouling under these circumstances is not severe since the zeolite beds are usually regenerated before much biological growth can take place. Backflushing and regeneration effectively removes the biological growths.

The presence of high magnesium concentrations in the feed water to the selective ion exchange process represents a significant problem with respect to the alkaline regeneration process. Fluidization of the bed by upflow regeneration and thorough backwashing is required to alleviate the $Mg(OH)_3$ fouling problem. High magnesium waters should preferentially be treated by selective ion exchange employing the neutral brine regenerant solutions of the electrolytic renovation process.

Selective ion exchange with electrolytic renovation of the regenerant will provide a very positive means of ammonia removal from wastewater. High ammonia removal efficiencies can be maintained in spite of variable feed composition and the presence of toxic substances which seriously affect biological nitrogen removal processes. If loss of control occurs in the ion exchange process, this can generally be quickly corrected and the process returned to normal operation within a few hours. Loss of control or upsets in the alternative biological nitrification-denitrification process can seriously reduce the efficiency of this process for several weeks until the proper biological flora can be reestablished. The selective ion exchange process is expected to be readily adapted to areas where cool weather in winter adversely affects ammonia stripping and biological nitrification-denitrification processes. It should also find application in areas where breakpoint chlorination cannot be used for total removal of ammonia due to the large amount of chloride salts which breakpoint chlorination introduces into the effluent discharge.

Design Assumptions

The regeneration process consists of elution of the ammonium ions (NH_4^+) by the addition of sodium in the form of NaCl. The regenerant is then clarified by the addition of soda ash to precipitate calcium as $CaCO_3$ to protect the cathode in the electrolysis cell from becoming fouled. The electrolysis process produces sodium hypochlorite (NaOCl) which reacts with the ammonia molecule, freeing nitrogen and forming NaCl. Additional salt (NaCl) must be added to make up the amount lost in the rinsing of the bed and the amount exchanged to the zeolite.

The power requirements for the zeloite process were assumed to average 40 watt hours/gram of ammonia-nitrogen destroyed. The average length of the service cycle was assumed to be 200 bv (gross bed volumes).

LAND DISPOSAL OF EFFLUENTS

Process Description

The terms "land disposal" or "land treatment" are used synonymously to mean the application of wastewater onto the land. Historically, land disposal involved application of raw sewage onto the land. Several major cities including Berlin, Melbourne, and Paris have used so-called "sewage farms" for the treatment and disposal of raw sewage.[203] However, little knowledge and understanding of the principles of geology, hydrology, climatology, or biology were utilized in these early attempts at land disposal. The only concern of the early users was to dispose of unwanted sewage. Early application methods were by flooding or ridge and furrow irrigation.

Beginning in the early 1950's, land treatment facilities were designed with awareness and consideration of the natural science disciplines mentioned above. Generally, raw sewage is no longer applied to the land without prior treatment. The trend is to apply treated effluent onto the land via one of the many conventional irrigation procedures. The type of irrigation system to be used depends on the amount and type of wastewater, the type of land, legal requirements, regulatory agencies, the public, and many other factors.

The application of treated wastewater effluents onto the land embodies the concept that wastewater contains nutrients which are resources that should be recycled back to the land.[5,203] The primary nutrients (nitrogen, phosphorous and potassium) found in wastewater are only slightly reduced in conventional primary and secondary treatment systems; hence these nutrients are normally released to surface water. Excess quantities of nutrients will act to stimulate the growth of algae in surface waters causing overgrowths or "blooms" which may be detrimental to fish and other aquatic inhabitants. Such excessive and undesirable growth of algae can create nuisances (e.g., odors), reduce the recreational value of the water, and increase the cost of water treatment.

Land disposal systems may be classified as either low rate or high rate systems. Low rate systems utilize wastewater application rates of approximately 2 to 10 ft/yr, while high rate systems achieve wastewater application rates of 150 to 350 ft/yr.[213]

Low rate systems are segmented into two types of application systems. Spray irrigation is defined[1] as the controlled spraying of liquid onto the land at a rate measured in inches per week, with the flow path of the liquid being infiltration and percolation through the soil. Overland runoff[1] is defined as the controlled discharge (by spraying or other means) of liquid onto the land at a rate measured in inches per week, with the flow path of the liquid being downslope across the land.

The Muskegon County (Michigan) Wastewater Management System (presently under construction) will be the first large scale low rate (sprinkler) effluent land disposal system in the U.S. Many consider it the prototype for increased utilization of land treatment technology. The system is designed to process 43.4 MGD of wastewater, about 24 MGD of which is from industrial sources (mainly pulp and paper mills). The system will include secondary treatment in a series of aerated lagoons, application of the effluent onto the land (6300 acres of flat, sandy soil) with long rotating spray booms, storage lagoons to accommodate 5 months flow (winter), a subsurface drainage system, and control and monitoring of all surface runoff and subsurface drainage. The loading rate will be 2.5 million gal/

acre/year or 7.7 ft/year over the total area. Extensive clearing of trees was required to adequately prepare the area for the irrigation system.[5] The estimated cost of the complete system is reported to be $42 million. This project will provide the opportunity to research many aspects of land treatment technology that have been overlooked or inadequately studied in the past.

High rate systems consist of rapid infiltration which is defined as the controlled discharge of liquid onto the land at a rate measured in feet per week with the flow path being high rate infiltration and percolation through the soil.[1]

Most high rate systems are in the Southwest. The basic purpose for most high rate systems is groundwater recharge. Generally, high rate systems utilize recharge basins where large volumes of water are pumped and held to allow for infiltration into the ground below. Major examples of this disposal technique are the Whittier Narrows plant near Los Angeles (15 MGD) and the Flushing Meadows project near Phoenix (1 MGD).

The land area required for sewage effluent disposal depends on the loading rate used. The loading rate in turn depends on many factors including:[5]

- The soil capacity for infiltration and percolation;
- Hydraulic conductivity (percolation capacity) of the root zone of cover vegetation;
- Evapotranspiration capacity of site vegetation; and
- Assimilation by soil and vegetation of nitrogen, phosphorus, suspended solids, BOD, heavy metals, and pathogenic organisms.

The infiltration capacity of the soil will limit the rate at which water can be applied to the area without runoff. Steeper slopes, previous erosion, and lack of dense vegetative cover will also reduce the infiltration capacity and necessitate a corresponding reduction in application rates.

The hydraulic conductivity of the soil in a vertical direction will determine the total precipitation and effluent application that can be transmitted to the groundwater. Increased precipitation in a wet year will reduce the amount of effluent which can be applied. Table A-7 shows the amount of water which can be applied to various soil textures under ideal conditions.

TABLE A-7

ESTIMATED MAXIMUM HYDRAULIC LOADING OF WASTEWATER EFFLUENT FOR VARIOUS SOIL TEXTURES (IDEAL CONDITIONS)[5]

	Movement Through the Soil Root Zone* Inches/Day	 Inches/Year
Fine sandy	15.0	300
Sandy loam	7.5	180
Silt loam	3.5	90
Clay loam	1.5	40
Clay	0.5	10

---

*Precipitation plus effluent less evapotranspiration

In order to provide sufficient soil material for renovation of the applied effluent, at least 4 feet of aerated soil is normally required in the root zone.[5]

The hydraulic conductivities and drainage capacity of the soil and geologic materials are of importance in determining the allowable loading rate. The drainage capacity of the soil/geologic material is important in determining the need of a drainage system to control the water table. If the capacity of the natural system is great enough to maintain the groundwater table at an acceptably low level (4 to 5 feet of aerated soil), then a subsurface drainage system is unnecessary. If the natural drainage is not great enough to provide this depth of aerated soil, an artificial subsurface tile drainage system will be required. A water table at or above the drain tile depth is required for a tile drainage system to remove any water. When the water table is below the drain tile depth, the only means to provide artificial drainage is by drainage wells.

In order to meet discharge limits to receiving waters, most of the nitrogen found in secondary effluent may have to be removed. Recent technical papers indicate many complex processes potentially available for removal of the various nitrogen forms in a soil system. However, only two basic processes are consistent for long time periods. Nitrogen can be removed by growing and removing from the area a crop which takes up the nitrogen, or by denitrification.

Effluent resulting from aerobic biological processes contains nitrogen principally in the forms of ammonia and nitrate. Nitrogen in the nitrate form is subject to movement with the water through the root zone and is not retained by the soil as the ammonia form can be.

Denitrification, which will provide added nitrogen removal, occurs naturally in soil systems. However, elaborate construction and control is required to accomplish predictable denitrification in soil systems. Even where control is maintained, the process will not operate at peak efficiency for 100 percent of the time. High rate land disposal systems can result in recharge of large volumes of treated wastewater to the groundwater, but appear capable of removing only about 30 percent of the influent nitrogen.

Phosphorus is removed by adsorption on the cation exchange complex, by precipitation and by sorption with iron and aluminum oxides. The removal of phosphorus is therefore dependent on the soil texture, the cation exchange capacity, the amount of iron and aluminum oxides and the uptake of phosphorous by the crop. Because of these removal mechanisms, little movement of phosphorous through the soil system with the drainage water is anticipated. Phosphorous concentrations in groundwater from subsurface drainage systems are seldom over 0.2 mg/l and seldom as low as .01 mg/l. Common concentrations of phosphorus in the water which has moved through the soil are expected to be in the range of .01 to .1 mg/l with midpoints of this range most common. Such concentrations will meet standards for receiving waters.[5]

The removal of pathogenic organisms from effluent, before discharge to the receiving water, is required for obvious reasons. In land disposal by sprinkler irrigation these organisms are subject to movement through the air as aerosols. The movement is aided because the water is sprayed upward into the air. The potential travel distance is dependent on wind velocity, sprinkler pressure, nozzle size, height of nozzle, and roughness of the vegetation or ground surface. Trees in the buffer strip, for instance, will substantially reduce the potential travel distance.

Under normal circumstances, pathogenic organism contamination by air transport is not expected to be a problem if an adequate buffer strip is provided around the irrigated area. To prevent possible contamination of flowing streams or adjacent private and public property, a buffer strip or "green belt" is provided for protection. The width of this buffer strip is dependent on vegetation conditions. Trees are about 4 times better than short vegetation in preventing wind movement of particles across an area.[5] The buffer should be at least 200 feet with 100 feet of trees. If trees cannot be provided, a buffer width of 400 feet is a minimum.[5]

The effectiveness of the soil in removing pathogens has been demonstrated. A removal of 95 percent of these organisms in the surface layer of 0.5 inches of soil would be expected, and 3 to 5 feet of vertical movement above the water table has been shown to be sufficient for nearly 100 percent removal. Although one study indicates that organisms have travelled to depths of 3 to 5 feet.[5]

Since a very high concentration of the pathogenic organisms are retained in the surface layer, a possible contamination of surface water exists when natural precipitation causes runoff.

In addition to pathogenic organisms, another public health hazard that must be considered when wastewater is applied to the land is heavy metals concentration. The variable and not insignificant concentrations of heavy metals in sewage effluent are shown in Table A-8.

Little is known of the fate of heavy metals in soil. Jenne[90] proposed that the principal factor in retention of the heavy metals is sorption on hydrous oxides of manganese and iron. It is expected, therefore, that there will be little migration in the soil. Nevertheless, the capacity of the soil to retain these elements must be limited and eventual heavy metal breakthrough to the groundwater must be considered when using sewage effluent as a source of nutrients. The possibility of surface water pollution by soil erosion or flooding of cropland must also be considered.

Heavy metal buildup in soils can be detrimental in two ways. Continued buildup in heavy concentration in the soil over long

TABLE A-8

TYPICAL VALUES OF HEAVY METALS AND BORON FROM SEVERAL SOURCES AND LIMIT FOR IRRIGATION WATER[5]

Element*	Tahoe	Coker	CRREL	Irrigation Limit
Boron (Bo)			.7	.75
Cadmium (Cd)			.1	.005
Chromium (Cr)	.0005	.16	.2	5.0
Copper (Cu)	.019	.25	.1	.2
Iron (Fe)	.030		.1	
Mercury (Hg)	.001		.005	
Manganese (Mn)	.034		.2	2.0
Nickel (Ni)	.026	.31	.2	.5
Zinc (Zn)	.026	.32	.2	5.0

* All values in mg/l
NOTE: No value shown = no data given

time periods can eventually sterilize soils and, thus, cancel the original intent of the effluent disposal operation. other detrimental effect involves potential concentration of heavy metals in the tissue of plants grown on land which has been subjected to waste spreading. Public health hazards could result directly from ingestion of vegetables, fruits, or grains grown on this land or indirectly from ingestion of meat from animals which have grazed on the land. Further research is needed concerning the toxicity of heavy metals to plants and on the human and livestock intake through the food chain resulting from concentration of heavy metals in plant tissues.[92] Methods of treatment for heavy metals removal may need to be considered.

Of the systems outlined above, spray irrigation was selected as the alternative for investigation since it appears to be the most versatile method of land disposal or treatment and incorporates significant removal of nutrients.

Spray irrigation relies on liquid infiltrating the soil surface and percolating through the soil, together with evapotranspiration from the surfaces of vegetation and evaporation from the soil surface. The major limiting factor in spray irrigation is infiltration capacity. Maintenance of infiltration capacity involves intermittent application of wastewater with intervening rest periods. A typical application schedule, and one that has been thoroughly studied and found satisfactory, is the one in use at Penn State University. Weekly applications of 2 inches of wastewater at a rate of 1/4 inch per hour for eight hours followed by 160 hours of rest. This application schedule requires 129 acres for the treatment of one million gallons of wastewater and was the schedule utilized for this study. It should be noted that this schedule is extremely conservative and will result in a substantial acreage requirement.

Factors which must be considered for the design of an irrigation disposal system for municipal wastewaters include:

- Land availability, location and topography
- Soil type, depth, and chemistry
- Cover crop
- Weather
- Pretreatment of wastewater
- Irrigation equipment.

There should be adequate amounts of land available within a relatively short distance from the municipality and it must be of proper topography to minimize problems of runoff.

The soil should be capable of absorbing large quantities of water and be capable of supporting the growth of a cover crop that has broad tolerance limits for water.

A good cover crop is often considered the most important part of the irrigation system. The cover crop protects the soil from compaction by the water droplets striking the soil. Without a cover crop, the droplets strike the soil and break it into fine particles which seal the surface. The cover crop also increases the surface area available for evaporation and transpiration of the wastewater and provides additional storage capacity for the water. Water is introduced into the soil through the root zone of the cover crop, and the root system controls erosion of the soil. It has been found in the past that the most desirable cover crop is dense grass or a combination of grasses such as reed canary, timothy and orchard grass. The cover crop must be harvested from the field periodically during the growing season.[214]

Water containing dissolved solids (salts), especially sodium, in high concentrations may alter the chemistry of the soil to an extent that it affects soil structure. Changes in soil structure affect permeability which may change the amount of water that can be applied to the land. Wastewaters applied to the land with high sodium content will cause binding of the soil.

During severe cold, water applied to the irrigation field does not enter the ground or evaporate, but instead becomes stored in "ice beds." The thickness of these beds varies with temperature and the length of time subfreezing weather is experienced. Ice beds of several feet thickness have been experienced in the Midwest. The presence of these ice beds is in itself no severe problem to operation of a properly designed system. Major difficulties appear when a spring thaw occurs. A fast thaw can create great difficulty in containing the ice melt.

Level or near level land is required in addition to a dike or system of dikes to contain the spring runoff. If permitted to enter the receiving water, the runoff would carry with it large quantities of organics and dissolved and suspended waste solids. The retained wastewater and solids deposited during the winter could become septic during the spring and cause odors; however, year around operation has not caused objectionable odors.

If the system is required to operate during cold winter months, an automated solid set irrigation system is recommended. Hand-moved systems are not practical with icing conditions that occur, and self-propelled pivot systems require constant maintenance during cold weather. Conventional impact rotating sprinkler heads tend to freeze up in cold weather, as do the large volume rainguns. Piping mains, laterals and risers that are susceptible to freezing need to have fast, positive drainage when not in use.

Design Assumptions

Based on the success of the Penn State University studies, an average application rate of 1/4 inch/hour with a maximum weekly application of 12 inches was assumed. Acreage requirement was assumed at 129 acres per million gallons, which includes a 200 ft protective buffer strip around the spray site. Slope of spray site was assumed at less than 15 percent, with no runoff. Minimum depth of aerobic soil zone was 4 feet of well drained soil, with no drain field required.

A perennial grass crop will be grown and harvested to remove nutrients. Costs reflect harvesting and profit from sale of crop.

An automated solid set irrigation system was assumed and distance from treatment plant to spray field was assumed at 1/2 mile.

DISINFECTION

Process Description

Public health laws require disinfection of treated sewage effluent before discharge to surface waters, land surface, or to certain types of underground disposal. Adequate wastewater disinfection is important in light of the large number of potential waterborne microbial diseases. Over 100 different viral types found in wastewater have been identified as potential carriers of these diseases. Microorganisms of interest include the bacteria: V. cholera, salmonella, and shigella; the viruses: infectious hepatitis, coxsackie A and B (32 types), reoviruses (3 types), ECHO viruses (34 types), adenoviruses (32 types), viral gastroenteritis, and viral diarrhea; and the parasite E. histolytica.

Disinfection of wastewater treatment plant effluents is most commonly achieved by addition of chlorine or chlorine compounds in sufficient quantity to result in a free chlorine residual of 0.5 mg/l after one hour of contact time.

Disinfection by addition of chlorine compounds such as calcium hypochlorite or sodium hypochlorite is accomplished by feeding from a stock solution of chemical through a proportioning pump. The pump may be either automatic or manually adjusted to the flow. Use of chlorine compounds involves troublesome chemical storage and handling, adds unwanted solids to the water and is relatively expensive. Application of this disinfection strategy is limited to very small flows and swimming pools.

By far the most common disinfection technique is use of chlorine gas either by direct feed or solution feed. Chlorine gas is a dangerous, toxic chemical that must be handled in accordance with procedures established by the Chlorine Institute. Copies of these procedures are available from the Chlorine Institute or the chlorine supplier. Chlorine accidents in wastewater treatment are rare.

Chlorine gas is available in steel pressure cylinders with sizes ranging from 100 lbs to 2000 lbs capacity. Single unit railroad tank cars are available in three sizes: 16, 30, 55 and 90 tons net. Multi-unit tank cars holding 15 detachable, one-ton cylinders are also available.

Direct feed chlorinators receive chlorine gas from the supply, reduce the pressure to less than atmospheric through a regulating pressure reducing valve and inject the gas directly into the waste stream through a venturi injector. The feed rate is either manually adjusted or proportioned automatically to the wastewater flow, and is controlled by a fixed or variable orifice through which the chlorine gas passes.

Solution feed chlorinators receive the chlorine gas from the supply, reduce the pressure to less than atmospheric and mix the chlorine into a water solution. The solution is then pumped or flows by gravity to the wastewater to be disinfected. Chlorine is soluble in water up to 10 percent by weight depending on the temperature. The rate of feed of the chlorine solution is either manually regulated or automatically proportioned to the wastewater flow. Chlorine gas is metered to the solution feed chlorinator through a fixed or variable orifice.

The amount of chlorine required to achieve the required free chlorine residual depends on the oxidizable organic or inorganic content of the wastewater, pH, and temperature. Treated municipal wastewater free of unusual or industrial wastes would be expected to require approximately 0.0042 pounds of chlorine gas per person or population equivalent per day.

Some contact period is required after the addition of the chlorine to allow time for disinfection and chemical reactions to take place. This time will vary with the dose of chlorine applied. Chlorine contact basins are normally designed to provide adequate mixing through baffling or stirring, and to retain the average flow for one hour. The remaining amount of free chlorine is measured by an electronic chlorine residual indicator or a simple color comparator test using orthotolidine as a color producing agent.

Chlorine disinfection does not destroy all disease producing organisms. Amoebic cysts and certain viruses survive chlorination at typical application rates. However, chlorination is one of the few available disinfection techniques that is economically feasible, relatively safe and can be designed to maintain a residual disinfecting capability. This residual activity persists as long as there is uncombined chlorine in the water.

Disinfection by chlorine can be carried out by relatively low skilled personnel following simple, printed instructions.

One of the major drawbacks with chlorination of wastewater results from the potential toxic effects subsequent discharges can have on aquatic life. Chlorine itself, hypochlorite, and various forms of chlorinated hydrocarbons and amines can be extremely toxic to fish and aquatic invertebrates. Receiving waters may suffer extensive damage in the vicinity of treatment plant outfalls.

Disinfection with chlorine will vary in effectiveness with the pH and temperature of the treated water because of the partition between the more effective HOCl species and OCl^-. The relation between these chemical species is given in Figure A-28. Hydraulic considerations determine the mixing time allowed before chlorinated effluents are discharged. Degree of disinfection is related to detention time as can be seen in Figure A-29. Disinfection efficiency is also tied to the concentration of ammonia, ammonia compounds, and suspended solids in effluent wastewaters. Increases in these constituents will cause commensurate increases in chlorine dose requirements to attain a given level of disinfection. This increase is related to the formation of chloramines when ammonia is present and the reduction of hypochlorite by organic suspended solids due to oxidation of the cell matter.

Design Assumptions

For the purposes of completing the profile sheets presented in this report, direct chlorination with chlorine gas was assumed. Doses were set from empirical data to maintain a final residual concentration of 0.5 mg/l chlorine.[19] Detention basins were sized for a 30-45 minute contact period. All outfalls were assumed to function under gravity flow unless effluent was to be pumped into a spray irrigation system.

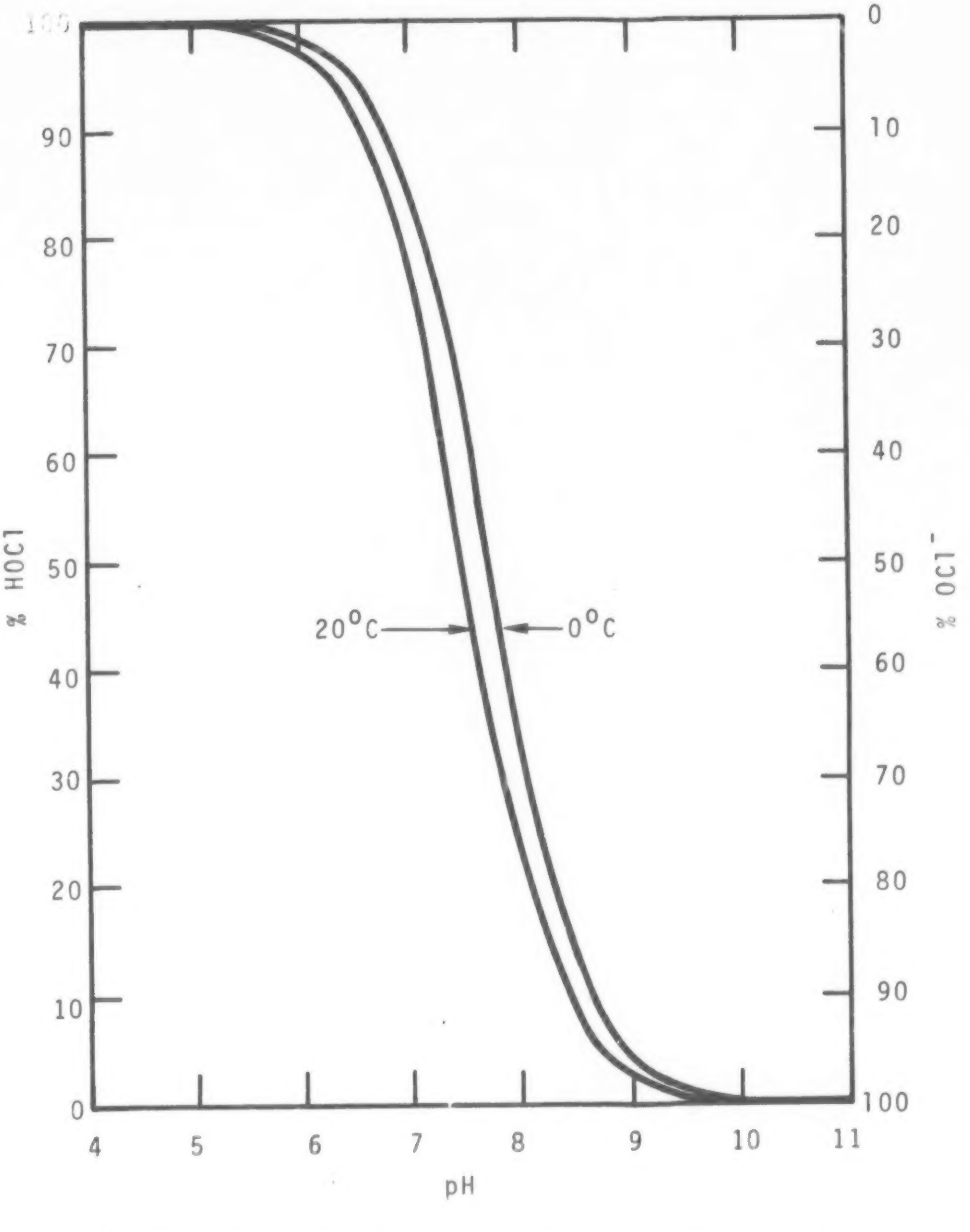


FIGURE A-28. RELATIVE AMOUNTS OF HOCl AND OCl^- FORMED AT VARIOUS pH LEVELS[4]

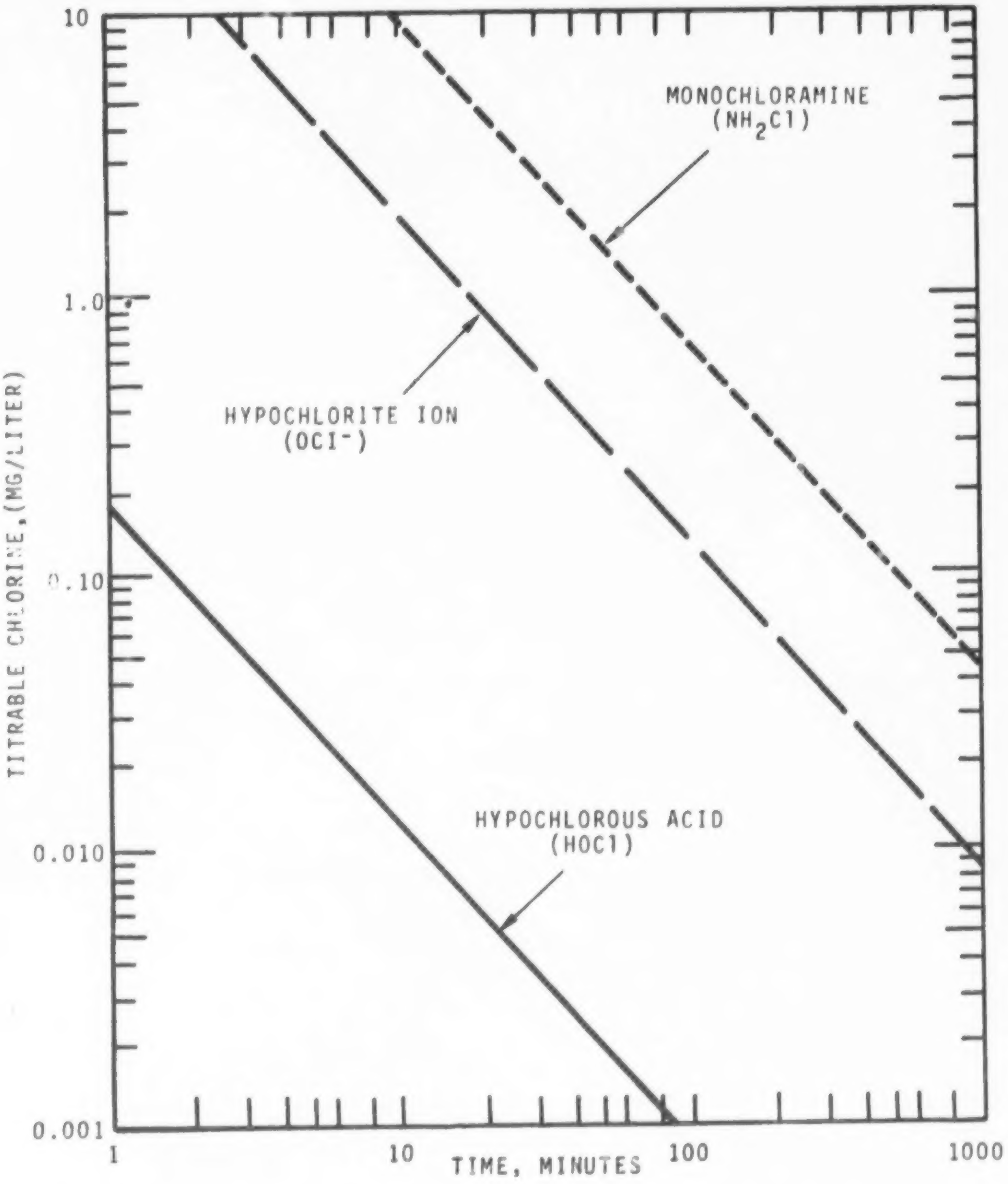


FIGURE A-29. RELATIONSHIP BETWEEN CONCENTRATION AND TIME FOR 99 PERCENT DESTRUCTION OF E. COLI BY 3 FORMS OF CHLORINE AT 2-6°C[215]

APPENDIX B

SLUDGE TREATMENT UNIT OPERATIONS

APPENDIX B

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APPENDIX B

SLUDGE TREATMENT UNIT OPERATIONS

GENERAL

The various sections of this appendix are designed to provide a description of each unit operation and its application, to present the major parameters involved in the design and/or installation of the unit, to discuss the important parameters (both physical and environmental) which affect the performance and operation of the unit, and to outline the general assumptions which were utilized in the development of the data presented in the profile sheets of this report.

The following unit operation general assumption sections, combined with the specific design parameters previously presented in the sludge option descriptors, are intended to provide sufficient information on the land and labor requirements and operating and capital costs of the sludge options to enable development of data for treatment plant sizes not evaluated in this report.

The unit operations discussions are presented in the order in which they are normally encountered on the sludge handling flow sheets. Sludge handling is initiated in the thickening operations and ultimate disposal methods terminate the process.

SLUDGE THICKENING

Sludge thickening is an operation whose primary purpose is to reduce the total volume of sludge by removing water. It is usually the most economical way to reduce total sludge volume and concentrate sludge solids. Advantages of sludge thickening are that it:

- reduces total sludge flow to subsequent sludge handling processes;
- allows equalization and blending of sludges thereby improving the uniformity of feed solids to subsequent treatment processes;
- improves primary clarifier performance by providing continuous withdrawal of sludge, thus insuring maximum removal of solids; and

- improves digester operation and cost because space is conserved, heating requirements decreased, detention period of existing units is increased, less supernatant liquor is produced, a higher solids loading per unit of digester volume is possible, and the microorganisms active in the digestion process are more efficient.

The two thickening techniques generally used are gravity or mechanical thickening and dissolved air flotation thickening.

Gravity Thickening

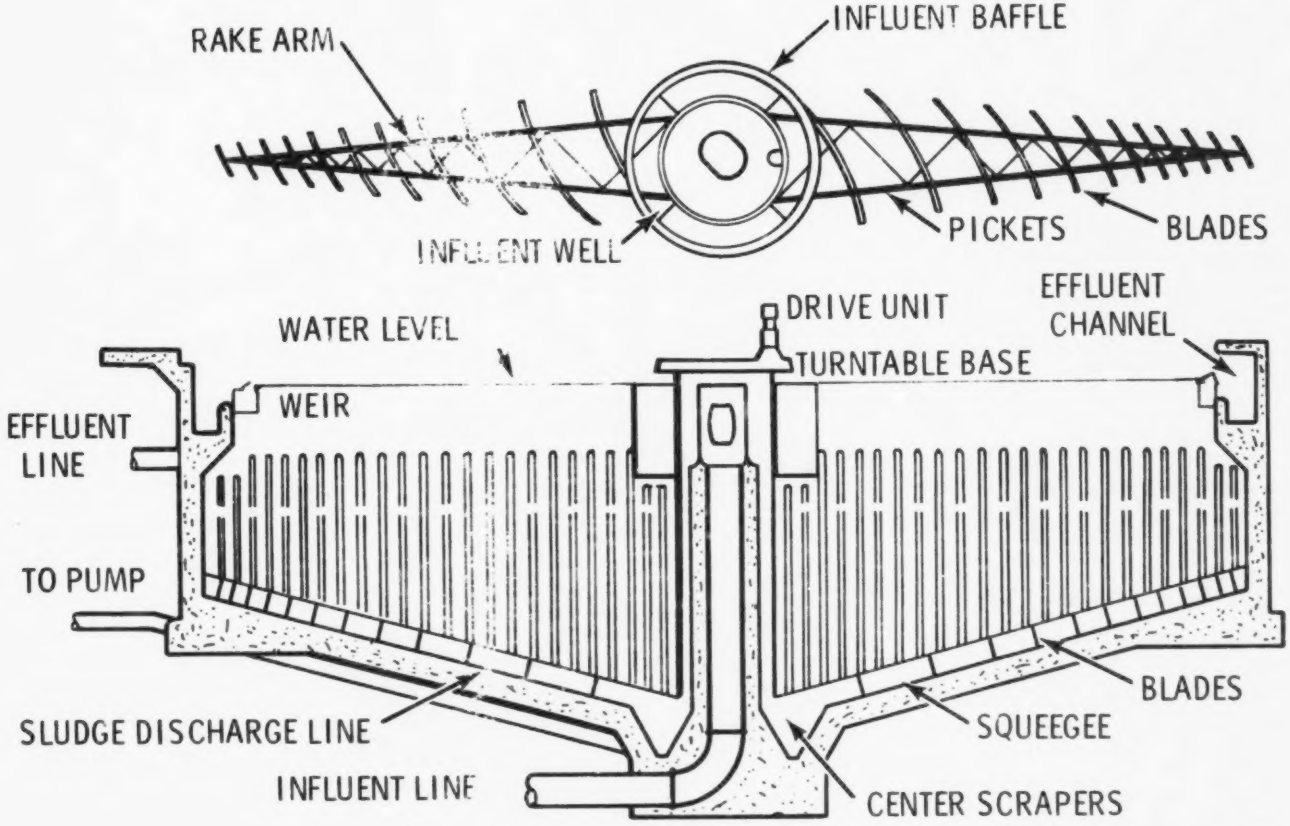
Operation Description

Thickening by gravity is the most common sludge concentration technique used in wastewater processing. It is a simple and inexpensive operation which can significantly reduce the volume of sludge requiring subsequent handling.

Gravity thickeners are similar to circular sedimentation basins in basic construction and in installed equipment such as bottom scrapers and surface skimmers. In general, gravity thickeners are deeper and have more steeply sloping bottoms than sedimentation basins. The unit is operated by continuously introducing the sludge to be thickened into a center feedwell. The sludge tends to settle to the bottom in a manner similar to that in a sedimentation basin. Attached to the rotating rake arms in most gravity thickeners are a series of vertical pickets as illustrated in Figure B-1. These pickets stir the sludge slowly and promote contact between the sludge particles causing an increase in particle size and improved settling characteristics. The steeply sloping floor and large sludge hopper promote accumulation of a concentrated sludge layer on the bottom of the thickener. Most gravity type thickeners, when operating on a waste amenable to this type of thickening, are able to produce maximum sludge solids concentrations of 8 to 10 percent.

The degree of concentration expected from a gravity thickening operation depends on several factors including type of sludge, use of chemicals, initial solids concentration, settling time, sludge temperature, sludge age, and operating conditions.

The difference between biological flocs and raw primary sewage provides a good example of the variations that can result from different treatment methods. Biological flocs (activated sludge) are bulky and concentrate to a lesser degree (2.5-3.0% solids) than raw primary sludge (8-10% solids). Moreover, it appears that mixtures of raw sludge and raw activated sludge do not gravity thicken well, but mixtures of raw sludge and secondary


RAKE ARM
INFLUENT BAFFLE
INFLUENT WELL
PICKETS
BLADES
WATER LEVEL
DRIVE UNIT
EFFLUENT CHANNEL
TURNTABLE BASE
WEIR
EFFLUENT LINE
TO PUMP
BLADES
SQUEEGEE
SLUDGE DISCHARGE LINE
INFLUENT LINE
CENTER SCRAPERS

SCHEMATIC PLAN OF THICKENER MECHANISM AND SECTION OF TANK

FIGURE B-1. TYPICAL GRAVITY THICKENER[53] sludge from biological filters do tend to thicken well (7-9% solids) in this process. In some cases chemicals, such as metal salts of the hydrous oxides or organic compounds known collectively as polyelectrolytes or polymers, are added to sludge to enhance thickening. Chemical addition does not always improve the thickening characteristics of sludge and, therefore, cannot be considered a panacea for sludge thickening problems. The effects of chemical addition on sludges should be determined in laboratory investigations and then confirmed in plant scale tests before implementation as a part of routine plant operation.

Investigations in the laboratory and in pilot and full scale operations indicate that optimum gravity thickener performance is achieved when feed solid concentration is in the 0.5 to 1.0 percent range.[10] Improved thickener performance also occurs as sludge temperature increases to 37°C.[10] At higher temperatures performance decreases.

Settling time and sludge age can be interrelated and have a definite effect on thickener performance. Up to a point, increasing settling time in a thickener results in increased underflow solids concentration. However, as sludge accumulates in deep deposits over long time periods, it tends to become septic, producing entrained gas and a bulky sludge which doesn't compact well. If the thickener feed sludge has been stored in the clarifier for a long period of time, the problem of potential septicity is aggravated. Malodor production is usually not a problem but can occur when septic conditions exist in the thickener.

The supernatant from gravity thickeners is usually mixed with raw wastewater as it enters the treatment system and, therefore, recycles through the entire treatment process. Since the volume of sludge is reduced to about 20 percent of its original volume, approximately 800 gallons of supernatant is returned for each 1000 gallons of sludge that enters the thickener. Gravity thickener supernatant generally has a suspended solids content of about 150 to 300 mg/l and a BOD of about 200 mg/l.[79] This added flow increases both the hydraulic and waste loadings on the treatment system.

Gravity thickener design is usually based on hydraulic surface loading rates and solids loading rates. Experience indicates that solids or mass loading generally governs the design. Typical solids loadings for gravity thickeners in lb/day/ft^2 are about 5 for activated sludge, 10 for waste activated-primary sludge mixtures, 10 for trickling filter sludge, 10 for trickling filter-primary sludge mixtures, and 20 for raw primary sludge.[4]

The dry solids ratio of waste activated to primary sludge governs the acceptable solids loading to be used in thickener design. As this ratio increases, the acceptable solids loading decreases.

Most thickeners are operated at hydraulic loadings of 600 to 800 gpd/ft^2 of surface area.[7][8] Thickeners with hydraulic loadings less than 400 gpd/ft^2 have been found to produce odors.

General Assumptions

The mass loading rate was utilized as the major design parameter. Surface loading rates were incorporated as limiting criteria with overflow rates of 400 to 800 gal/sq ft/day and a detention time of six hours utilized.

The mass loading rate for a particular sludge depends upon the sludge's characteristics and, therefore, a general, all inclusive value does not exist. Values for the sludge types analyzed are presented in the sludge option descriptions.

Acreage requirements for installation of sludge thickeners were assumed to be twice their surface area. Operation and maintenance costs were assumed to be $2.60 per ton of dry solids to the thickener.[10] Capital cost figures are installed equipment costs provided by Eimco Division of Envirotech Corporation.

Flotation Thickening

Operation Description

The second major type of sludge thickening in current use is dissolved air flotation thickening. Flotation thickening is not normally used for primary sludges since this type of sludge can usually be concentrated more economically in gravity thickeners. Flotation thickening has, however, become quite popular for use in thickening secondary sludge such as waste activated sludge, secondary sludge from biological filtration and mixtures of activated and primary sludges.

Basically the process consists of introducing the sludge flow into a chamber wherein it is intimately mixed with a source of water in which large amounts of air have been dissolved. Under the high pressures involved, a considerable amount of air actually goes into solution. When the pressurized water and the sludge are mixed in the thickening tank, the pressure on the water instantly drops to approximately atmospheric pressure. This decrease in pressure creates a new equilibrium solubility for air in water which is lower than that which prevailed when the water and air were under high pressure. As a result, all dissolved air in excess of the new equilibrium value is released from solution in the form of millions of very tiny bubbles. These air bubbles tend to attach themselves to particles of sludge thus causing the sludge particles to be buoyed to the surface of the thickening unit. The sludge is then scraped by skimmers from the surface of the thickening unit into a chamber from which it can be pumped or otherwise removed for further treatment.

Most flotation thickeners are also equipped with a mechanism for collecting sludge which settles in the bottom of the thickening unit. Normally, very little organic matter settles to the bottom of flotation thickeners. In some cases, however, a considerable amount of grit and large solid particles may be collected on the bottom of the thickening unit. These materials are usually scraped to one end of the thickening unit from which they may be periodically pumped together with the thickened "float" (solids) for further treatment. A schematic of a typical flotation thickener is shown in Figure B-2.

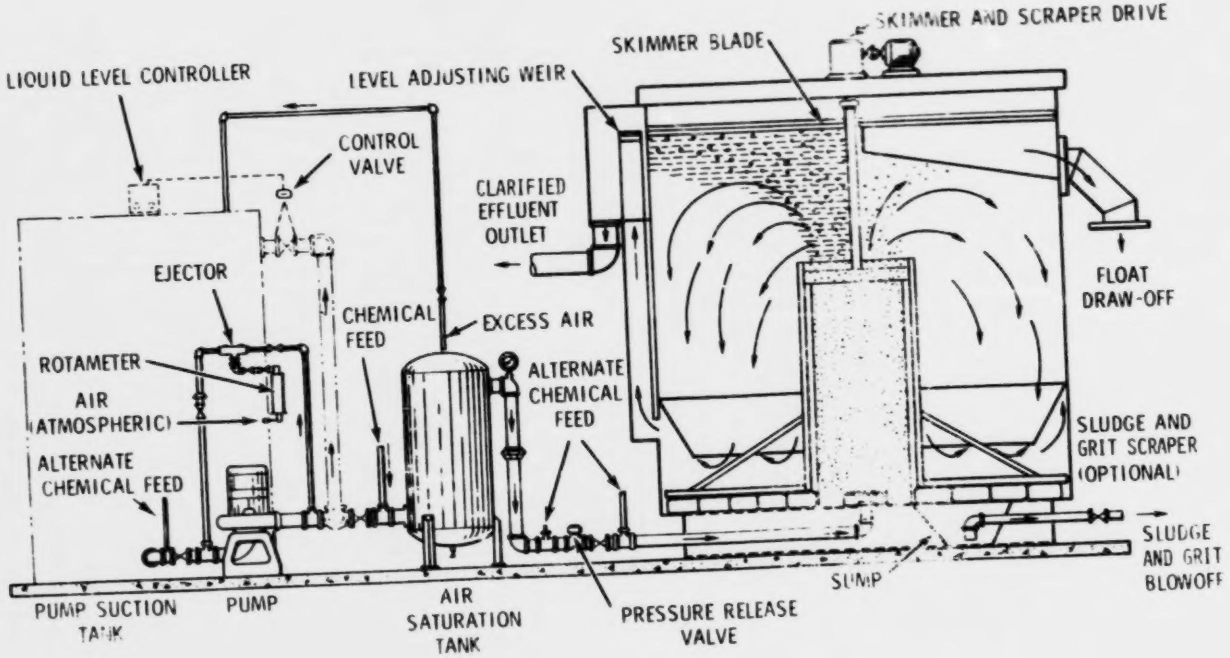
The primary variables for flotation thickening are (1) pressure, (2) recycle ratio, (3) feed solids concentration, (4) detention period, (5) air-to-solids ratio, (6) type and quality of sludge, (7) solids and hydraulic loading rates, and (8) use of chemical aids.

Air pressure used in flotation is important because it determines air saturation and the size of air bubbles formed, and it influences the degree of solids concentration and the subnatant (separated water) quality. In general, increased pressure, or air, produces greater concentrations and lower effluent suspended solids concentration. There is an upper limit, however, since too much air breaks up fragile flocs.

The recycle ratio and feed solids concentration are interrelated. Additional recycle of clarified effluent does two things. First, it allows a larger quantity of air to be dissolved because there is more liquid, and second, it dilutes the feed sludge. Dilution reduces the effect of particle interference on the rate of separation, thus increasing the concentration of floated solids.

The concentration of sludge increases and the effluent suspended solids decrease as the sludge blanket detention period increases. Experience has shown that there is a rapid increase in solids concentration with detention times up to 3 hours.[10] Beyond 3 hours little additional thickening is experienced.

Increasing air/solids ratios lead to increases in floated solids production. Eventually, with unlimited use of air, a ratio can be reached where no further increase in concentration would be possible.


SKIMMER AND SCRAPER DRIVE
SKIMMER BLADE
LIQUID LEVEL CONTROLLER
LEVEL ADJUSTING WEIR
CONTROL VALVE
CLARIFIED EFFLUENT OUTLET
EJECTOR
CHEMICAL FEED
EXCESS AIR
FLOAT DRAW-OFF
ROTAMETER
AIR (ATMOSPHERIC)
ALTERNATE CHEMICAL FEED
ALTERNATE CHEMICAL FEED
SLUDGE AND GRIT SCRAPER (OPTIONAL)
SLUDGE AND GRIT BLOWOFF
SUMP
PUMP SUCTION TANK
PUMP
AIR SATURATION TANK
PRESSURE RELEASE VALVE

Reproduced from best available copy.

FIGURE B-2. SCHEMATIC OF A DISSOLVED AIR FLOTATION THICKENER[77]

As in gravity thickening, the type and quality of sludge to be floated affects process performance. Flotation thickening is most applicable to activated sludges but higher float concentrations can be achieved by combining primary with activated sludge.

Unit loading rates naturally affect the performance of flotation thickening units. In general, higher loadings impair the performance of thickening units.

As with gravity thickening units, it is sometimes necessary to add chemical thickening aids in order to achieve satisfactory operation of flotation units. In the wastewater treatment field, flocculating chemicals have agglomerated solids into stable flocs that promote increases in the terminal velocity and facilitate capture of gas bubbles. The overall effect is to increase the allowable solids loadings, increase the percentage of floated solids, and increase the clarity of the effluent. Cationic polyelectrolytes (polymers) have been the most successful chemicals used in sewage sludge thickening.

As the supernatant from gravity thickeners is recycled through the treatment process so is the subnatant from flotation thickeners recycled. The operation of several laboratory dissolved air flotation units resulted in floated sludge and subnatant suspended solids concentrations of 25,900 to 44,600 mg/l and 800 to 1100, respectively, at influent suspended solids of 7900 to 10,000 mg/l.[79] This solids loading and attendant BOD and hydraulic loadings add to overall treatment process loading.

Solids loading is the design parameter governing the surface area of the flotation unit. Design loadings for flotation units are about 2.0 lbs dry solids/ft^2/hr and 0.8 gpm/ft^2 hydraulic loading.[4]

Other parameters utilized in design of units for flotation thickening of domestic sewage sludges are listed below.[64]

1) Influent Solids Concentration (weight percent) = 1.0-2.0

2) Effluent (Float) Solids Concentration (weight percent) = 4.0

3) Air to Solids Ratio (lbs air/lb solids) = 0.02

4) Air Flow Rate (ft^3 air/lb dry solids/hr) = 0.3

5) Total Hydraulic Loading (sludge gpm/ft^2 + recycle gpm/ft^2) = 2.0

6) Recycle Ratio = 2.5

General Assumptions

The flotation thickening parameters are for the dissolved air pressure flotation method. Flotation thickening was considered only for those cases comprising a mixture of activated and primary sludges.

Assumed design parameters were:

1) Air to Solids Ratio - 0.02-0.04 lbs air/lbs solids
2) Loading Factor - 2 lbs/sq ft/hr
3) Sludge Hydraulic Loading - 0.8 gpm/sq ft
4) Total Hydraulic Loading - 2.0 gpm/sq ft

Operating and maintenance costs for flotation units were based upon a range of $11.70-14.30/ton of dry solids.[10] These costs include costs for chemical coagulants to promote increased solids capture. Capital cost figures represent installed equipment costs provided by the Eimco Division of Envirotech Corporation.

ANAEROBIC DIGESTION

Operation Description

Anaerobic digestion is a biological process used for the controlled destruction of biodegradable organic materials in sewage sludges. The process requires an oxygen free atmosphere for development of the proper microbiological population, which is responsible for the actual digestion of the organic solids. The primary objective and advantage of anaerobic digestion is production of an inoffensive, biologically stable sludge suitable for subsequent disposal. Other advantages of the process are sludge volume reduction and production of a combustible gas mixture (methane and carbon dioxide) which can be used as an energy source to offset the cost of plant operations.

As mentioned above, anaerobic digestion of sewage sludge must be carried out in the absence of free oxygen since the microorganisms responsible for the actual stabilization of the wastes are very sensitive to oxygen and are inactivated by its presence. In the process, living organisms break down the complex molecular structure of the solid material in the sludge. This biodegradation process causes release of much of the water content of the solids and provides nutritional and energy requirements for the organisms' life processes. As a result, the putrescible solids are converted into more stable organic and inorganic solids.

In theory, the process of anaerobic digestion may be thought of as occurring in two different phases. The first phase which occurs rather rapidly is called acid fermentation. In this phase the microorganisms attack complex organic materials in the sludge converting these materials to simpler organic acids (volatile acids), hence the name acid fermentation. Since the end products of this first stage of digestion are acid in nature, the pH of the sludge mass in the digester tends to be lowered. If other phases of digestion did not occur simultaneously, the entire process would be stopped by the production of organic acids and the attendant lowering of pH to the point where conditions would be too severe for continued microbial activity.

The second phase of digestion is called the methane production phase and should occur simultaneously with the first phase. Methane bacteria attack organic acids and other degradation products from the first phase to produce the mixture of methane and carbon dioxide gases. The methane gas is highly flammable and has considerable fuel value which can be utilized as a source of power or heat.

The necessity that the two phases of digestion occur simultaneously can be likened to a factory production line where one group of workers condition and stockpile material for use by a second group who turn out the finished product.

The most important advantages of anaerobic waste treatment are the high degree of waste stabilization obtained and the low degree of conversion of organic matter to biological cells. The small mass of microorganisms produced in the process minimizes the problems of biological sludge disposal, as well as the requirements for inorganic nutrients such as nitrogen and phosphorus.

In an anaerobic digester, the quantity of waste converted to microorganisms decreases with increasing sludge detention time. When cells are maintained for long periods of time, they consume themselves for energy, with the result that net growth is less. Thus, greater waste stabilization and lower biological cell production is obtained at long sludge retention times. Long retention times also result in higher efficiencies of treatment.

The anaerobic digestion process is sensitive to the following parameters:

- pH
- Sludge temperature within the digester
- Volatile solids concentration in the feed sludge
- Digester detention time

- Adequacy of sludge mixing within the digester
- Presence of inhibitory or toxic substances in the system.

The methane forming bacteria are extremely pH sensitive and optimum digestion cannot occur outside a range of pH 6.8 to 7.4 (refer to Figure B-3). In addition to being pH sensitive the methane bacteria are temperature sensitive and, under normal circumstances, function best in a narrow temperature range of 90 to 98°F. They are extremely sensitive to sudden changes in temperature and temperature fluctuations of as little as 3°F over a short period of time can upset the process.

In general, the higher the sludge volatile solids content, the more efficient digestion becomes. Therefore, attempts are made to digest as thick a raw sludge as possible. A maximum feed concentration is considered desirable because:

- It conserves heat by minimizing water content,
- It prevents dilution of the sludge buffering capacity,
- It concentrates the microorganisms' food supply thereby increasing their efficiency,
- It increases digester detention time, and
- It minimizes the supernatant volume returned to other treatment plant processes.

The reaction time required to anaerobically stabilize sewage sludge is quite long and varies with temperature (refer to Figure B-4). A properly designed and operated anaerobic digester can accomplish this stabilization in 20 to 30 days; therefore, anaerobic digestion systems are usually designed with a detention time of approximately 25 days. Since system detention time is the design method of providing the microorganisms enough time to properly do their jobs, it is imperative that sludge flows through anaerobic digesters not be allowed to increase to the point where the system is hydraulically overloaded. Hydraulic overloading results in lower detention times and, therefore, lower process efficiencies.

Digester contents should be well mixed. Adequate mixing keeps microorganisms functioning at peak efficiency because they are in continuous contact with their food supply. In addition, mixing keeps the concentration of biological end products uniform, prevents scum accumulation, improves temperature uniformity throughout the sludge mass and distributes any toxic substances throughout the tank volume thereby reducing their concentration. Mixing can be accomplished either mechanically or by gas recirculation.

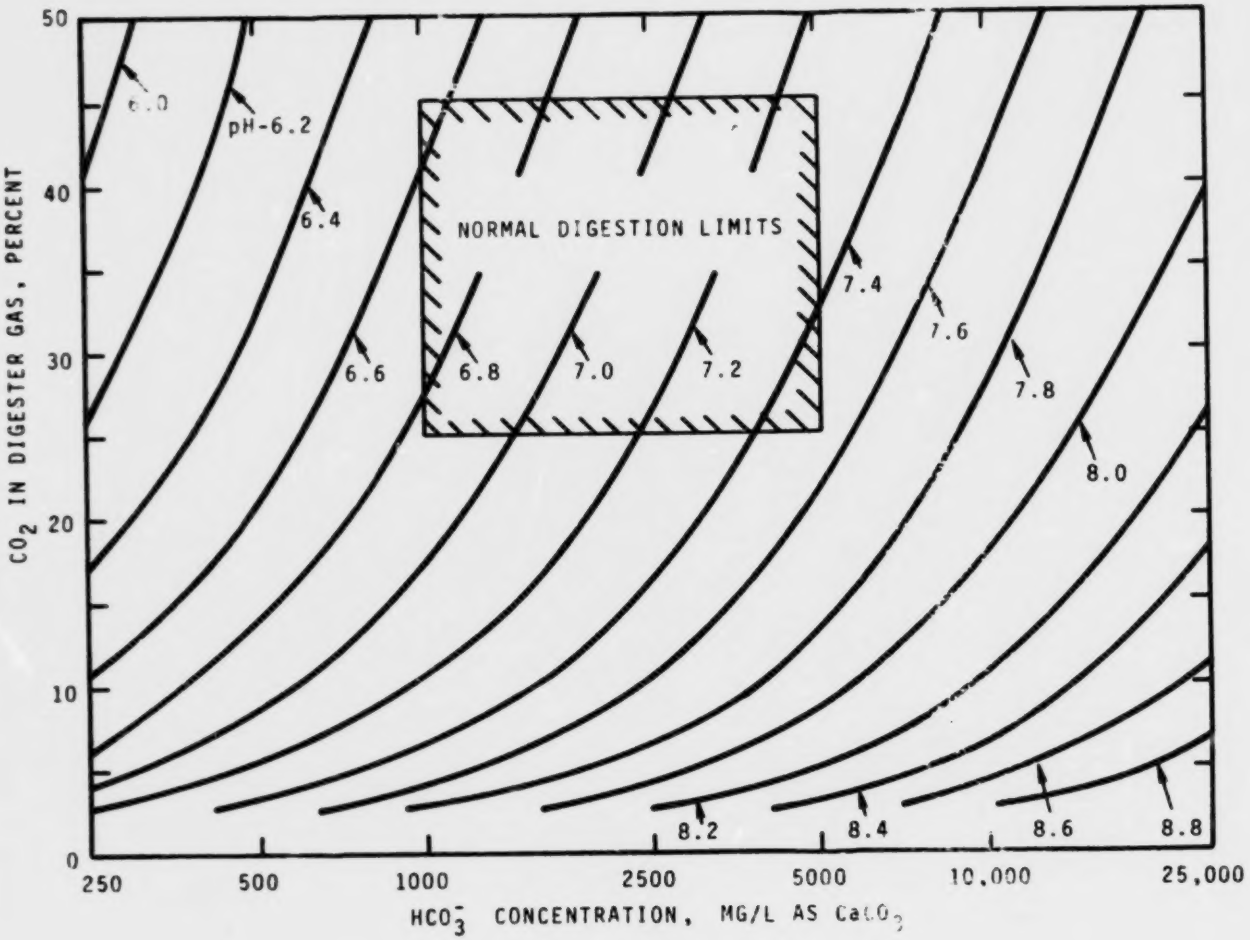


FIGURE B-3. pH and BICARBONATE CONCENTRATION RELATIONSHIP[214]

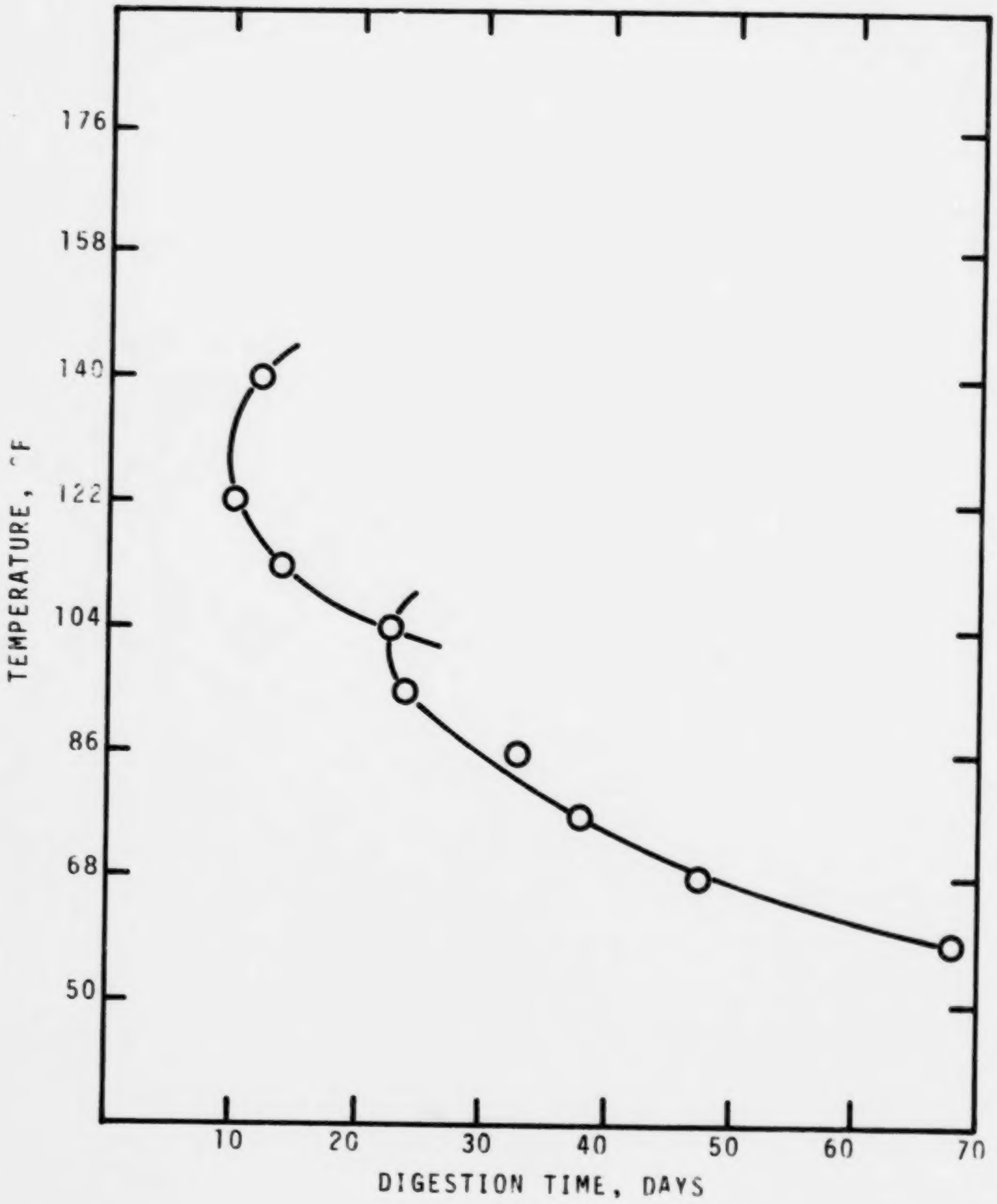


FIGURE B-4. DIGESTION TIME-TEMPERATURE RELATIONSHIP[10]

There are many materials, both organic and inorganic, which may be toxic or inhibitory to anaerobic digestion. The degree of inhibition or toxicity is strongly dependent on the concentration of the substance with the effect usually increasing as concentration increases.

In addition, the chemical form in which the substance exists can be of importance as illustrated by the inhibition of the methane bacteria by the unionized fraction of volatile acids. Some of the more common inhibitory substances present in the anaerobic digestion process are:

- Soluble sulfides - These can result from (1) introduction of sulfides with the raw waste or (2) formation in the digester from reduction of sulfates. The latter method is especially important in those coastal areas where there is a substantial infiltration of sea water into the sewer system. The approximate limit at which inhibition begins to occur is about 100 mg/l of soluble sulfide.
- Salt toxicity - Most of the common cations can be inhibitory if present in high enough concentrations. This is rarely observed in domestic sewage sludge digestion except in those cases where too high a concentration of base containing sodium, potassium, calcium, or magnesium is used for pH adjustment.
- Ammonia toxicity - Ammonia is formed in anaerobic digestion from the breakdown of proteins and, at the pH usually found in digestion, is present almost entirely as the cation, NH_4^+. High concentrations of either NH_3 or NH_4^+ can be inhibitory to the process; however, these concentrations are rarely attained in the digestion of domestic sewage sludge.
- Heavy metals - Low concentrations of the heavy metals, such as copper, zinc, and nickel, can cause digester failure; however, only the soluble form of the heavy metal is toxic and the concentration of soluble sulfides in the digester is frequently high enough to convert the heavy metals to their insoluble form which is non-toxic.

Concentrations of some substances which will cause toxic conditions during sewage sludge digestion are shown in Table B-1.

During the first ten days of digestion, the rate of destruction of volatile matter is extremely fast when compared with the subsequent rate. This early period is characterized by high volatile solids reduction and the release of large volumes of methane and other gases. The activity within the digester

TABLE B-1

CONCENTRATIONS WHICH WILL CAUSE A TOXIC SITUATION IN WASTEWATER SLUDGE DIGESTION[20]

Substance	Concentration, mg/l
Sulfides	200
Heavy Metals*	>1
Sodium	5,000- 8,000
Potassium	4,000-10,000
Calcium	2,000- 6,000
Magnesium	1,200- 3,000
Ammonium	1,700- 4,000
Free Ammonia	150

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*Soluble

is so violent during this period that separation of liquid from the digesting solids is extremely difficult. After approximately ten days the rate of gas production and biological activity slows down considerably and, under these conditions, it is much easier to separate liquid from the solids and to compact the solids. For this reason, digestion is quite often carried out in two separate tanks. The first tank is usually called the primary digester and is the reaction vessel for the most active biological degradation. In order to optimize reaction conditions within the digester, it is normal to install mixers and a means for heating the sludge. After the prescribed reaction time, the sludge overflow from the primary digester is pumped into another digester which is normally referred to as a secondary digester. There the biological activity and gas production proceed at a much slower rate and favorable conditions are established in order to promote separation of liquid from the digester solids and to allow concentration of the digester solids in the bottom portions of the tank.

Supernatant from the secondary digester is normally recycled through the plant's liquid treatment processes. Such supernatants contain a significant quantity of volatile solids, organic matter, and high concentrations of nutrients (particularly nitrogen and phosphorus). Chemical analysis of a typical digester supernatant is shown in Table B-2.

The organic and solids loading on the liquid treatment process will be increased considerably by recycle of such supernatants.

The anaerobic digestion process has had the reputation, in municipal waste treatment, of being somewhat more unstable and more difficult to operate than other biological processes.

However, the process does have many advantages and, when properly operated, is stable as evidenced by its successful use in larger municipalities such as New York, Chicago, and Los Angeles. Smaller communities have experienced more difficulty with the process. Possible reasons for these problems are: (1) lower dilution of toxic materials because of less and more variable wastewater flows; (2) lack of qualified operators; and (3) inadequate process control.

TABLE B-2

CHEMICAL ANALYSIS OF ANAEROBIC DIGESTER SUPERNATANT[20]

Parameter	Concentration, mg/l
pH	7.1
Total Solids	4,985
Total Volatile Solids	3,300
Suspended Solids	2,905
Volatile Suspended Solids	2,530
COD	5,407
Total Carbon	3,075
Total Organic Carbon	1,624
Ortho - PO_4 (as P)	91
Total Phosphate (as P)	141
NH_3-Nitrogen (as N)	818
Organic Nitrogen (as N)	282

The process would be adversely affected by loss of electrical power for a long period of time. Complete loss of electricity would inactivate the equipment used to pump sludge to the heaters. Hot water recirculation pumps in the heat exchanger and sludge mixing equipment would also be inactivated. The total loss of electricity for long periods of time is unlikely since most sewage treatment plants are equipped with a source of emergency electrical power. Also, public utilities have an excellent record of locating and correcting problems in their distribution systems.

General Assumptions

Anaerobic digestion of raw sludge was assumed to be a prerequisite for any ultimate disposal scheme which did not include incineration. Anaerobic digestion rather than aerobic digestion of sludge was selected for evaluation since it is presently the most common method utilized and achieves a high degree of waste stabilization. Furthermore, anaerobic digestion provides significant destruction of pathogenic bacteria and adequate odor control. For these reasons it is thought that anaerobic digestion will be the most frequently used means of digestion for the next decade. However, other methods of sludge treatment are presently under investigation and may prove to be more beneficial and less costly.

Two stage anaerobic digestion was assumed with a design detention time of twenty-five days at 90°F.[63] Operating and maintenance costs were based on a range of $2.4-$4.4 per ton of dry solids.[10] Capital costs were based on installed equipment costs. Figure B-5 graphically presents construction costs based on digester volume.[54]

Construction costs per unit of digester volume were assumed to decrease as total volume increases up to a maximum volume of 400,000 cubic feet. Four hundred thousand cubic feet is thought to be the practical construction limit for two digesters with associated control building.

Manpower requirements were taken from Figure B-6.[54]

SLUDGE CONDITIONING

Sludge conditioning is a chemical or physical means of changing the characteristics of a sludge in order to improve its dewatering capabilities. Normally, the intended transformation is from an amorphous gel-like sludge mass into a porous material which will quite freely give up its entrained water.[53]

Numerous sludge conditioning methods exist, some of which are:

- chemical addition - polymer and/or inorganic
- physical-heat treatment
- freezing of sludge
- admixtures (addition of fly ash, etc.)
- elutriation

Present trends indicate that chemical addition and physical heat treatment (by the Porteous or low pressure Zimpro methods) hold the potential of being the most popular means of conditioning sludge during the next decade. Hence, these two methods were chosen for detailed study within this report. However, this is not intended to imply that other methods, possibly not even previously mentioned, will not gain wider acceptance and utilization in the future.

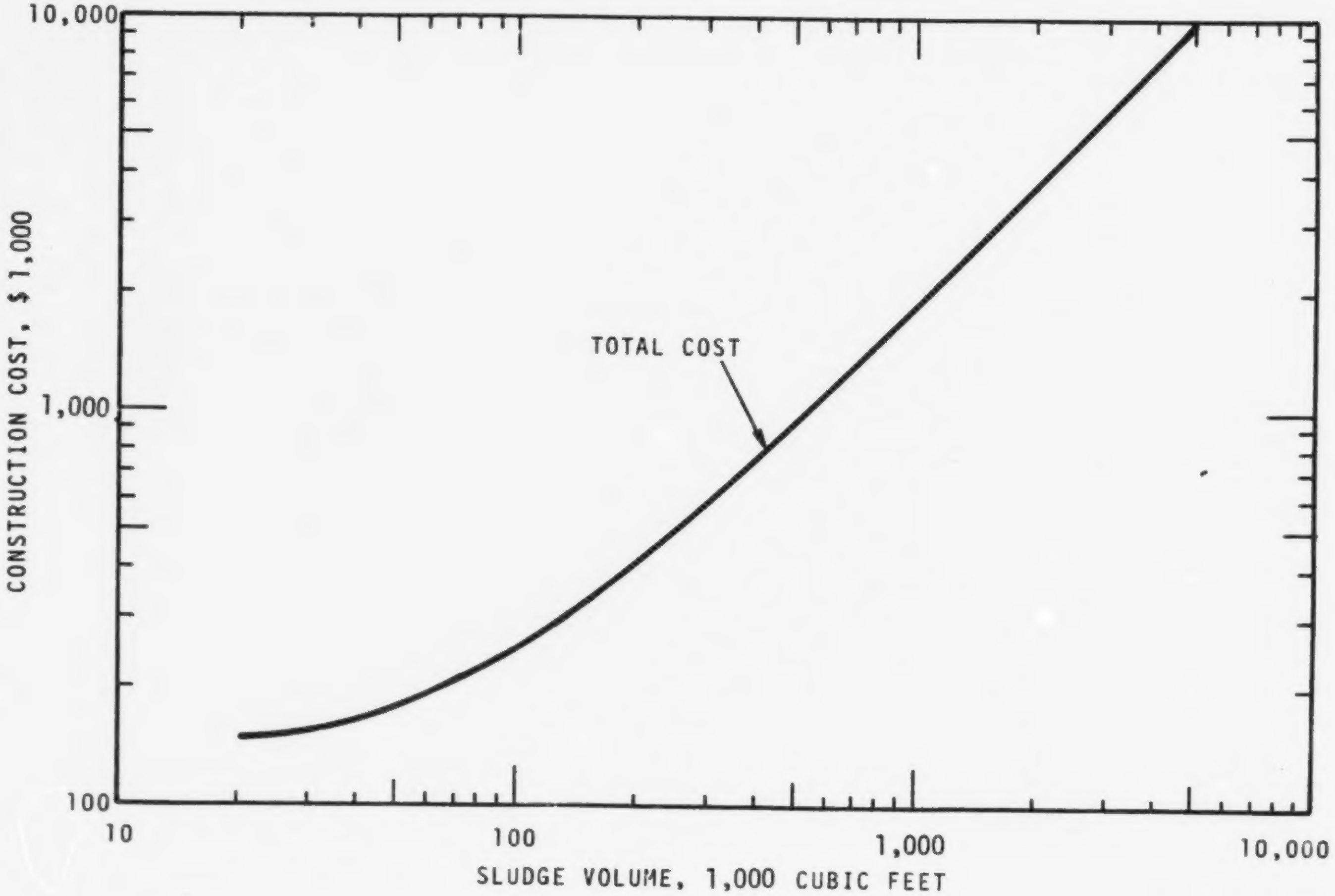

FIGURE B-5. SLUDGE DIGESTION DIGESTERS AND CONTROL BUILDINGS, CONSTRUCTION COSTS[54]

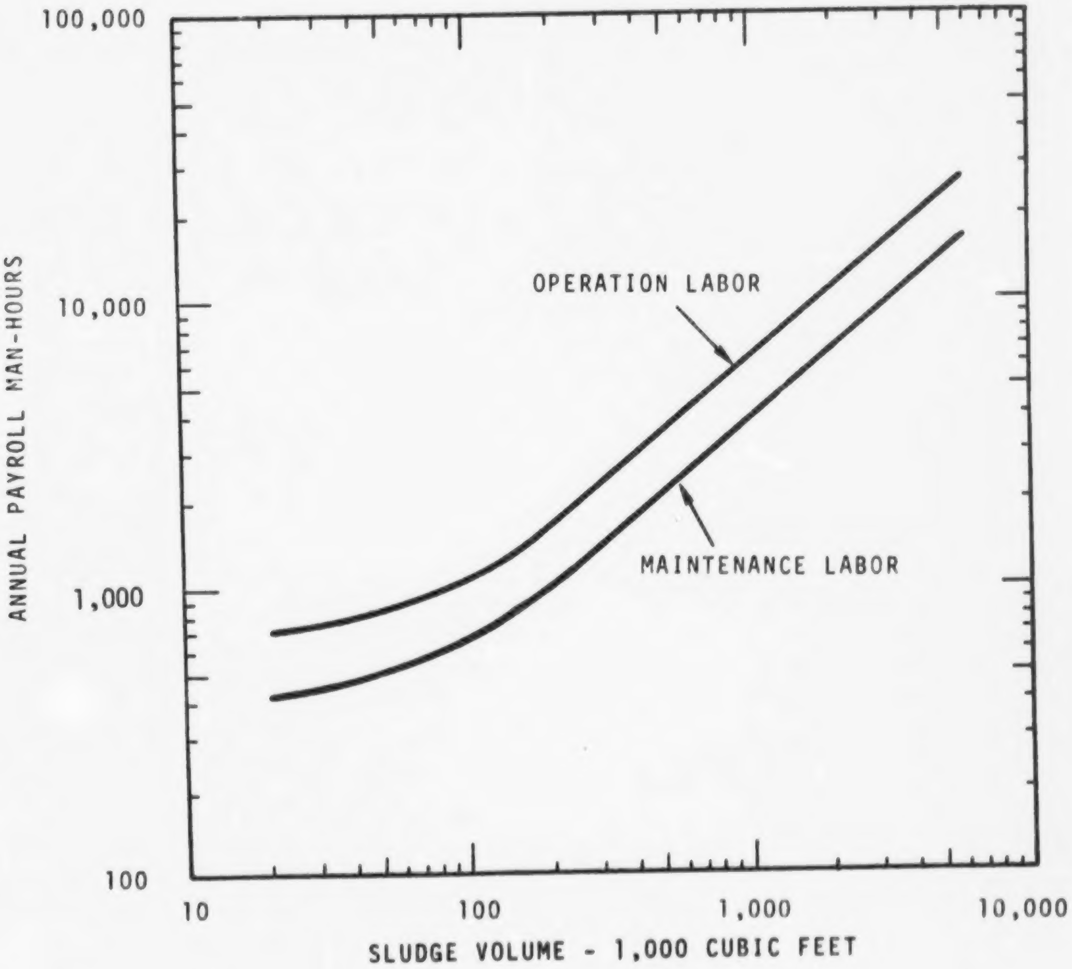

FIGURE B-6. SLUDGE DIGESTION, MAN-HOUR REQUIREMENTS[54]

The objective of sludge conditioning varies with the dewatering process. For example, vacuum filtration functions most efficiently with an open structured sludge with high permeability. Furthermore, the sludge must demonstrate a distinct resistance to compression in order to retain its permeability when a pressure differential is applied to the sludge cake by the vacuum filtration equipment.[53]

Chemical Conditioning

Operation Description

Present sludge conditioning technology has not reached a high level of exactness and, therefore, the selection of the correct chemical conditioner is still a trial and error process. Furthermore, daily fluctuations in sludge characteristics can significantly alter the effectiveness of the chemical conditioner being utilized. Chemical treatment usually involves coagulation-flocculation of sludge solids with polymerized hydrolysis products of multivalent metal ions (such as $FeCl_3$ or $FeSO_4$) and/or natural or synthetic organic polymeric materials to form an agglomerated, expanded structure.[53]

The efficiency of chemical conditioning is greatly affected by pH and it may be necessary, with highly buffered sludges, to utilize lime as the conditioning agent or to employ elutriation (washing and diluting methods) to the sludge before the addition of a chemical coagulant.[53] The latter method involves the addition of low alkalinity water which is mixed with the sludge and decanted in order to lower the level of alkalinity.

The use of synthetic organic polyelectrolytes (polymers) for sludge conditioning is gaining wide acceptance. Synthetic organic polymers are high molecular weight, long chained, water soluble substances and may be cationic, anionic or ampholytic. Organic polymers are thought to agglomerate sludge solids by adsorption.[53] Generally, cationic polymers are used for sludge conditioning.

A comparison of different sludge conditioning agents for vacuum filtration has been tabulated by Weston[20] for various types of sludges and is shown in Table B-3. The data includes dose rates, initial and final solids concentrations and filter yields. From this data there appears to be a significant difference between the amount of polymer required versus the amount of inorganic chemical necessary for adequate conditioning. Although inorganic chemical doses can range up to 20 percent by weight of dry

TABLE B-3

VACUUM FILTRATION RESULTS COMPARING INORGANIC CHEMICALS WITH PURIFLOC C-31 ON MUNICIPAL SLUDGE[20]

	Location	Type of Sludge	Type of Filter	Filter Media	Chemical Conditioning	Dosage lbs/ton dry solids	Solids Concentration Initial percent	Solids Concentration Final percent	Filter Yield lbs/sq ft /hr	Increase in Yield Due to Use of Polyelectrolytes percent
1.	Municipal STP	Raw primary	K-S	coil	FeCl3 Lime	162.4 166.8	7.57	20.1	6.91	
	Municipal STP	Raw primary	K-S	coil	C-31	14.0	7.0	20.0	7.53	9
2.	Municipal STP	Raw primary	K-S	coil	$Fe_2(SO_4)_3$ Lime	60 106	9.1	24.0	8.6	
	Municipal STP	Raw primary	K-S	coil	C-31	8.4	9.6	20.0	11.5	34
3.	Municipal STP	Raw primary	Eimco drum	open synthetic	$FeCl_3$ Lime	80.0 280.0	15	40.0	5.0	
	Municipal STP	Raw primary	Eimco drum	open synthetic	C-31	18.0	12	30.0	7.0	40
4.	Municipal STP	Raw primary	Eimco drum	open synthetic	$FeCl_3$ Lime	78.0 390.0	11.2	39.0	3.1	
	Municipal STP	Raw primary	Eimco drum	open synthetic	C-31	20.0	10.7	34.5	3.5[1]	13
5.	Atlanta, Clayton	Digested primary	D-O drum	long napped dacron	$Fe_2(SO_4)_3$	($6.06/T)	7.2	26.0	3.9	
	Atlanta, Clayton	Digested primary	D-O drum	long napped dacro	C-31	($6.58/T)	7.2	33.5	11.0	182
6.	Municipal STP	Digested primary	drum	44 x 44 saran	$FeCl_3$ Lime	66.0 206.0	15.0	43.0	9.2	
	Municipal STP	Digested primary	drum	44 x 44 saran	C-3.	17.0	15.0	32.0	25.0	172
7.	Municipal STP	Elutriated/digested/primary	D-O drum	napped polyester	$FeCl_3$	56.8	6.1	36.0	5.74	
	Municipal STP	Elutriated/digested/primary	D-O drum	napped polyester	C-31	10.2	7.7	32.9	12.66	121
8.	Municipal STP	Elutriated/digested/primary	D-O drum	napped polyester	$FeCl_3$	100.0	10.4	32.7	3.88	
	Municipal STP	Elutriated/digested/primary	D-O drum	napped polyester	C-31	8.0	10.1	38.6	5.94	53
9.	Municipal STP	Elutriated/digested/primary	Eimco drum	napped polyester	$Fe_2(SO_4)_3$	[illegible]	10.9	34.0	2.8	
	Municipal STP	Elutriated/digested/primary	Eimco drum	napped polyester	C-31	9.3	11.1	35.0	5.5	96
10.	Atlanta-South River	Elutriated/digested/primary and secondary	D-O drum	long napped dacron	Lime $Fe_2(SO_4)_3$	($8.9[illegible]) ($8.7[illegible]/T)	9.1	25.0	4.7	
					C-31		9.1	24.0	7.4	57
11.	Municipal STP	Digested primary and secondary	Eimco	synthetic	$FeCl_3$ Lime	610.0 [illegible] or ($10 [illegible])	4.4	26.2	5.2	
	Municipal STP	Digested primary and secondary	Eimco	synthetic	C-31	18.0 ([illegible]/ton)	4.3	23.7	5.6	8
12.	Municipal STP	Elutriated/digested/primary and secondary	D-O drum	napped dacron	$Fe_2(SO_4)_3$ Lime	36.0 120.0	3.0	28.0	5.1	
	Municipal STP	Elutriated/digested/primary and secondary	D-O drum	napped dacron	C-31	22.0	9.0	25.0	7.25	42

---

[1] Yield intentionally kept down to avoid overloading incinerator

sludge solids as compared to 1 percent for polymers, the cost per ton of inorganic chemicals can be appreciably lower.[53] With the advent of new polymers and improved production methods, the cost of polymers may decline in the future. The costs for chemical conditioning reported herein reflect average prices, and it should be noted that these figures may differ significantly from region to region.

General Assumptions

All chemical costs and quantities listed on the profile sheets for sludge conditioning are based on the utilization of organic polymers rather than inorganic chemicals such as ferric chloride or lime.

In general, polymers have produced acceptable results when utilized as conditioning aids. However, the type of polymer or inorganic chemical to be used for successful conditioning varies from location to location and must be evaluated for each specific situation.

Porteous Process

Operation Description

Heat treatment is a conditioning process that involves heating the sludge for short periods of time under pressure. The Porteous process is one of several heat treatment methods employed for sludge conditioning. Heat treatment coagulates the solids, breaks down the sludge's gel structure and reduces the hydrophilic (water affinity) nature of the solids.[55] This permits rapid dewatering without the need for chemical additives.

The process begins by pumping the sludge through a grinder which breaks up large solid particles (see Figure B-7). The sludge is then passed through a heat exchanger to a reaction vessel where steam is directly injected into the sludge. The sludge is retained in the reaction vessel for a period of approximately 30 minutes at temperatures ranging between 350-390°F and pressure between 180-210 psi.[55] The hot conditioned sludge is then passed back through the heat exchanger, giving up its heat to the incoming sludge. Finally, it is decanted and settled for removal of the conditioned solids. The "cake" is removed for further dewatering stages, and the supernatant is recycled back into the headworks of the treatment plant.

Reports indicate this process is capable of reducing moisture content to 35-70 percent (after dewatering) while producing a compact, sterile sludge.[7] Furthermore, the weight of influent solids is reduced by approximately 30 percent (dry weight basis) via the destruction of biological solids.

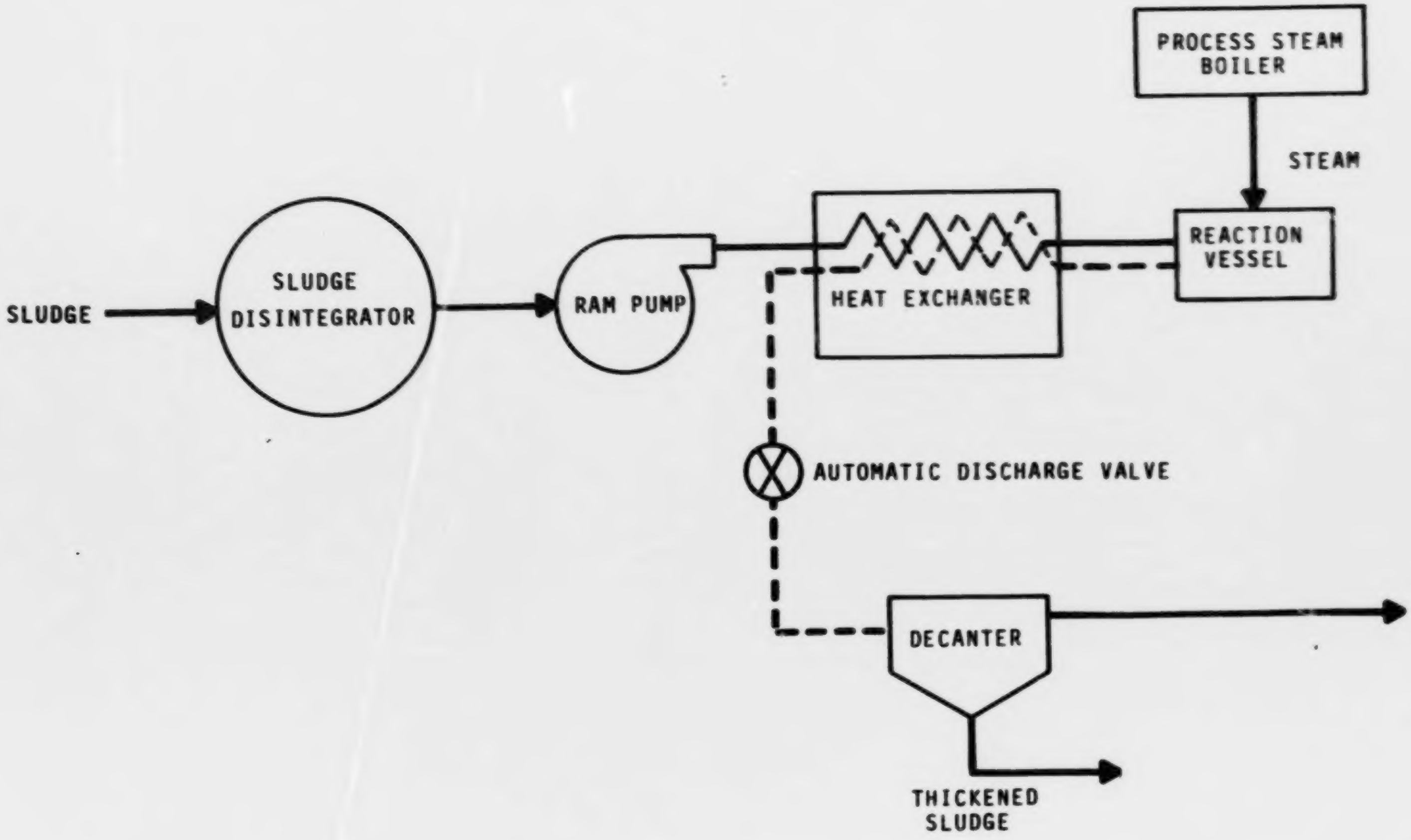
PROCESS STEAM BOILER
STEAM
SLUDGE
SLUDGE DISINTEGRATOR
RAM PUMP
HEAT EXCHANGER
REACTION VESSEL
AUTOMATIC DISCHARGE VALVE
DECANTER
THICKENED SLUDGE

FIGURE B-7. PORTEOUS PROCESS FLOW DIAGRAM[57]

The destruction of biological solids or organisms releases cellular contents back into solution in the liquor from the process, resulting in high suspended solids concentrations (2200-4000 mg/l) and BOD (3000-4000 mg/l). Also, the liquor contains significant concentrations of phosphorus and nitrogen from the cellular contents. Recycling of this high strength waste liquor back to the treatment plant represents a significant increase in the load reaching the treatment system. Furthermore, the portrate liquor is highly colored and odiferous. The dark color of the portrate will cause coloring of effluent which may be difficult to remove. The Santee Project in California experienced coloring of their effluent due to recycled portrate and had to discontinue this procedure.[18] The additional nutrient load from the recycled portrate liquor may significantly increase the chemical dosage requirements for phosphorus removal.

The system is sensitive to the percent volatile content of the sludge, the percent inert material, the moisture level and several physical parameters (i.e., clogging, electrical failures). The higher the volatile content, the better the treatment results. The cell structure will be disrupted and improved dewatering characteristics will be achieved. If large amounts of inert material exist in the influent, the heat treatment process will be relatively ineffective. Also, a low percent solids value in the inflow will result in poor effluent characteristics.

General Assumptions

Although there are several types of sludge heat treatment schemes which are commercially available, the Porteous process was selected as being representative, and evaluation of heat treatment was based on this process.

In general, a thirty percent decrease in total dry solids can be expected from the process due to biological cell destruction and liquification. A conservative vacuum filter yield of 8 lbs/sq ft/hr was assumed for all sludges conditioned by the Porteous process. Higher filter yields have been reported, but a comprehensive evaluation of process performance involving various types of sludges was lacking; therefore, the preceding value was utilized for this report.

Operating and maintenance costs reflect a range of $1 - $2 per ton of dry solids processed.[59,62] Capital costs that are shown herein are based on installed values.

CENTRIFUGATION

Operation Description

Centrifuges provide a means of dewatering waste sludges. Of the numerous existing designs, the solid bowl centrifuge is the most popular since it is considered to have the best combination of clarification and dewatering properties.

The solid bowl centrifuge, schematically illustrated in Figure B-8, consists of a cylindrical conical shell with a contoured scroll conveyor rotating at a slightly faster speed than the bowl. The infeed enters the hollow shaft of the helical conveyor and is distributed by ports into the bowl. The solid particles are centrifugally settled against the internal bowl wall and the liquid is transported to the centrate discharge located at the large diameter end of the bowl. The rotating scroll will convey the settled solids along the interior wall of the centrifuge to the solids discharge port. The conical portion of the centrifuge acts as a drainage deck causing further dewatering of the sludge.[53,61]

The performance of a centrifuge is normally reflected in the percent moisture of the sludge cake formed and the total percent solids recovered. Numerous parameters affect the overall degree of dewatering and some of these parameters and their affects are summarized in Table B-4.

TABLE B-4

SENSITIVITY OF VARIOUS CENTRIFUGATION VARIABLES
ON SOLIDS CAPTURE AND DEWATERING[53]

Variable	Effect of Increase in Variable on: % Solids Recovery	Effect of Increase in Variable on: Cake Solids Concentration
Machine Variables		
Bowl speed	Increase	Increase
Pool depth	Increase	Decrease
Scrolling speed	Decrease	Decrease
Process Variables		
Feed rate	Decrease	Increase
Feed concentration	Decrease	Increase
Temperature	Increase	Increase

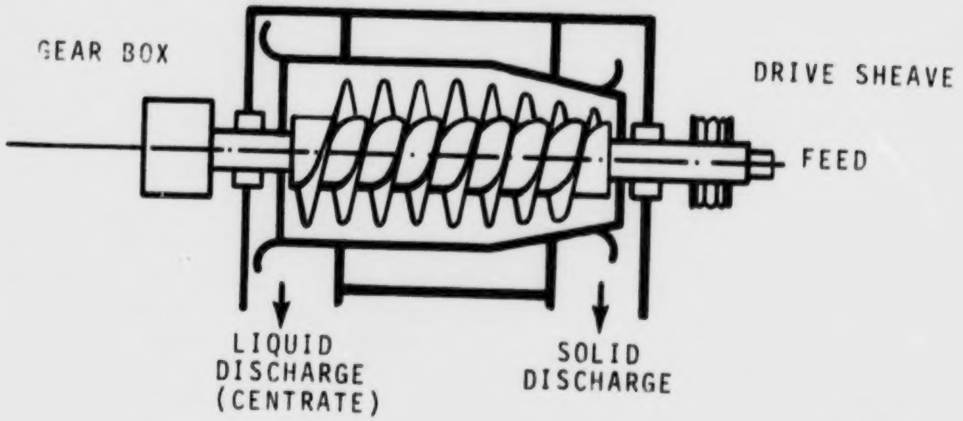
GEAR BOX
DRIVE SHEAVE
FEED
LIQUID DISCHARGE (CENTRATE)
SOLID DISCHARGE

FIGURE B-8. SOLID BOWL CENTRIFUGE[20]

Dewatering performance of a centrifuge varies with the type of sludge being handled. Typical cake concentrations and solids recovery levels with and without chemical addition are illustrated in Table B-5.

TABLE B-5

RESULTS OF CENTRIFUGATION OF SLUDGES[53]

Type of Sludge	Cake Concentration (% solids)	Solids Recovery (%) Without Chemicals	Solids Recovery (%) With Chemicals
Raw primary	28-35	85-90	>95
Digested primary	25-35	80-90	>95
Activated	6-10	---	---
Raw primary and activated	18-24	50-80	>95
Digested raw and activated	18-24	50-70	>95

Centrate disposal represents the major difficulty encountered with the use of centrifuges. Normally the centrate is relatively high in suspended, nonsettleable solids. The recirculation of centrate to the treatment system will add significant quantities of fine suspended solids to the process stream, resulting in a corresponding reduction in effluent quality. Several methods exist for controlling the quantities of fine solids recirculated. Longer residence time within the centrifuge results in increased solids capture. This is accomplished by either reducing the feed rate or increasing the bowl diameter of the centrifuge. Chemical coagulation of the sludge prior to centrifugation will increase particle diameter aiding in settling and increased solids capture.[31]

Centrifuges present several advantages to the plant operation, some of which are:[61]

- small area requirements;
- rapid startup and shutdown capabilities;
- easy adaption to changing feed conditions;
- potential low maintenance costs when proper grit protection is provided;
- independence from climatic conditions; and
- potential utilization for classification.

In general, centrifuges have been found to dewater fibrous and chemical sludges easily, but have had difficulty dewatering biological sludges.[61] As in the case of vacuum filtration, pilot tests are recommended as the most appropriate means of assessing the applicability of centrifugation for dewatering a particular sludge.

General Assumptions

In all cases, chemical conditioning prior to solid bowl centrifugation was assumed necessary. However, in actual practice the requirements for chemical additives before centrifugation will vary and may be nonexistent. Chemical conditioning requirements are dependent upon the characteristics of the sludge being processed and thus must be determined for each particular municipal wastewater sludge on a case-by-case basis.

The area requirement to provide adequate space for auxiliary equipment and normal maintenance and operation was assumed to be three hundred percent of the overall physical size of the centrifuge.

Operation and maintenance costs are based on a range of \$3.9-\$10.4 per ton of dry solids.[10] Capital costs reflect installed centrifuge values and associated auxiliary equipment. Figure B-9 illustrates construction costs of centrifuges based on hydraulic capacity.

Manpower requirements are shown in Figure B-10.

SAND DRYING BEDS

Operation Description

Sand drying beds are used to dewater digested sludge. Normally, sludge is placed on the beds in an 8 to 12 inch layer and allowed to dry. After drying, the sludge is removed for ultimate disposal, usually in a sanitary landfill. The economical use of sand drying beds is generally limited to small or medium sized communities. For populations over 20,000, consideration should be given to alternative means of sludge dewatering. Land costs, the cost of removing the sludge and replacing sand, and the large area requirements preclude the use of drying beds in large municipalities.[31]

Open beds are used where adequate area is available sufficiently isolated to avoid complaints caused by occasional odors. Covered beds with greenhouse types of enclosures are used where it is necessary to dewater sludge continuously throughout the year regardless of the weather, and where sufficient isolation does

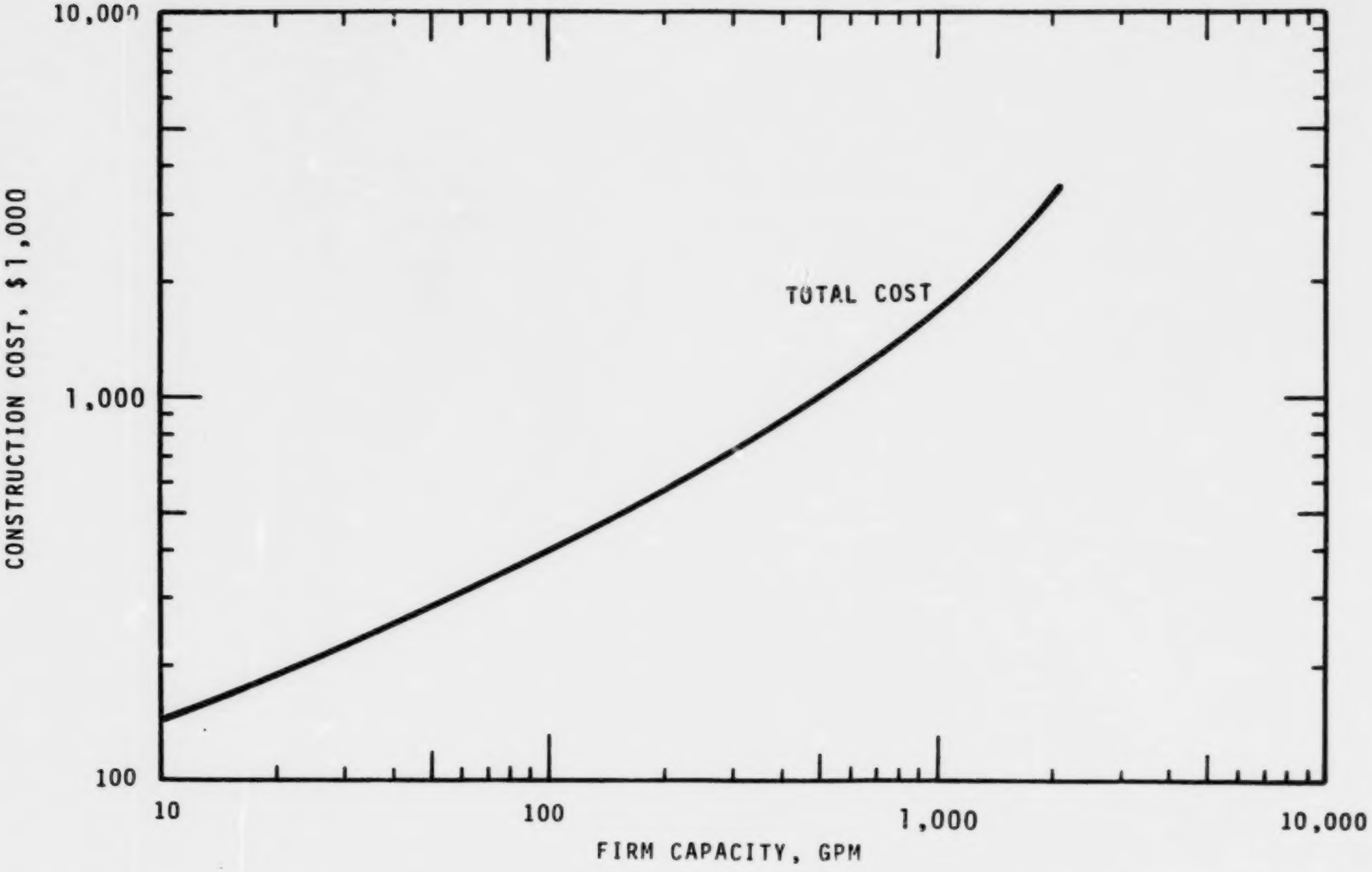

FIGURE B-9. CENTRIFUGATION, CONSTRUCTION COSTS[54]

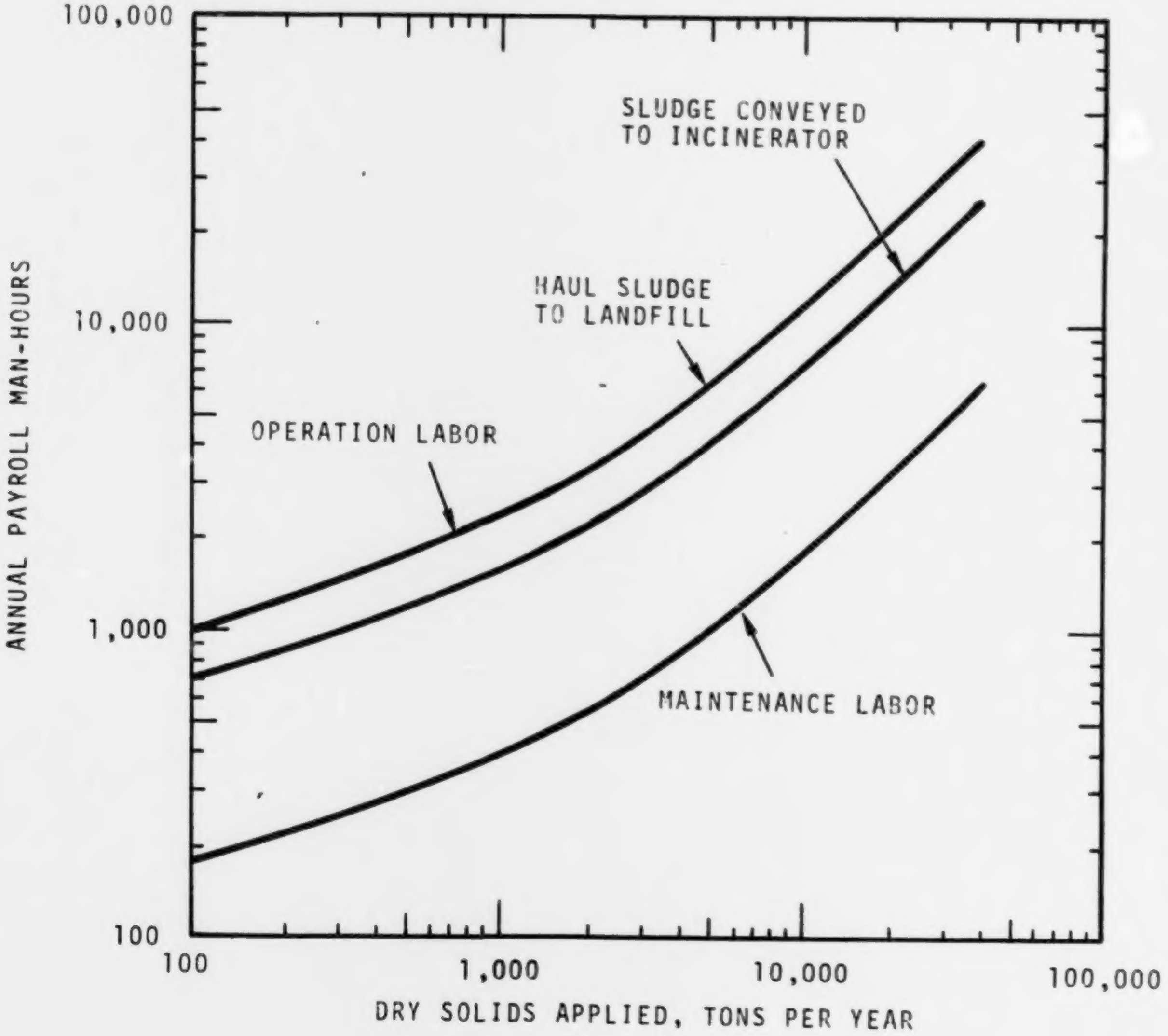

FIGURE B-10. CENTRIFUGATION, MAN-HOUR REQUIREMENTS[54] not exist for the installation of open beds. Well-digested sludge discharged to drying beds should present no odor problem, but to avoid nuisance from poorly digested sludge, sludge beds should be located at least 200 feet from dwellings.[31]

Sand bed loadings are computed on a per capita basis or on a unit loading of pounds of dry solids per square foot per year. Typical solids loading rates vary from 10 to 25 lb/ft^2/year for open beds to 12 to 40 lb/ft^2/year for covered drying beds.[31] With covered drying beds, higher sludge loadings can be accommodated because of the protection from rain and snow.

Sludge dewaters by drainage through the sludge mass and supporting sand and by evaporation from the surface exposed to the air. Most of the water leaves the sludge by drainage, so an adequate underdrainage system must be provided. Drying beds are equipped with lateral drainage tiles (vitrified-clay pipe laid with open joints) spaced 8 to 20 feet apart.[31] The tiles should be adequately supported and covered with coarse gravel or crushed stone. The sand layer should be from 9 to 12 inches deep with an allowance for some loss during sludge removal operations.[31]

Sludge can be removed from the drying bed after it has drained and dried sufficiently to be shoveled. Dried sludge has a coarse cracked surface and is black or dark brown. The moisture content is approximately 60 percent after 10 to 15 days under favorable conditions.[31] Sludge removal is accomplished by manual shoveling into wheelbarrows or trucks or by mechanized collectors such as scrapers and front-end loaders.

The use of drying beds are affected by numerous parameters such as:

- weather conditions,
- sludge characteristics,
- land values and proximity of residences, and
- use of sludge conditioning aids.

Climatic conditions are very important. Factors such as amount and rate of precipitation, percentage of sunshine, air temperature, relative humidity, and wind velocity determine the effectiveness of sludge drying on sand beds. The latter four combine to dictate the rate of evaporation. Weather, being uncontrollable, prevents the establishment of a reproducible scientific dewatering procedure.

When exposed to air, sludge will dry to an equilibrium moisture content. This equilibrium or final moisture content depends upon the temperature and relative humidity of the air in contact with the sludge and the nature of the water content. A high bound water (water retained in capillaries and in cell or fiber walls) will result in a high equilibrium moisture content.[80]

Evaporation of water occurs primarily by convection or air drying. This drying occurs in three stages: a constant rate stage, a falling rate stage, and a subsurface drying stage. During the constant rate period, the sludge surface is completely wetted and the rate of evaporation is independent of the nature of the sludge. This rate will be approximately the same as evaporation from a free liquid surface and will depend primarily on the air temperature, air velocity, and the relative humidity.

When a critical moisture content is reached, water no longer reaches the surface of the sludge as rapidly as it evaporates and a falling rate will occur. The rate of drying during the falling rate period will be a function of the thickness of the sludge layer, the physical and chemical properties of the sludge and the atmospheric conditions. This period is followed by subsurface drying until the equilibrium moisture content is reached.

Evaporation is particularly important one to two days after sludge is applied to beds because most of the drainage is completed by that time. After a few days the sludge cake shrinks horizontally producing cracks at the surface which accelerate evaporation by exposing additional sludge surface areas. Cracking also enhances drainage. While rain lengthens the drying time, its effect is less important if the sludge has dried to the point of cracking.

In locales which experience extremely cold winters where sludge would remain frozen for long periods of time, other means of sludge dewatering must be employed or sludge must be stored until climatic conditions are favorable for air drying. However, alternate freezing and thawing of sludge encourages dewatering, so treatment plants in areas which experience these climatic conditions could operate drying beds throughout the year.

The nature and moisture content of the sludge discharged to drying beds affects the drying process. It is important that sewage sludge be well digested for optimum drying. In well digested material, entrained gases tend to float the sludge solids while leaving a layer of relatively clear liquid that readily drains through the sand. The more water removed by drainage, the less is required to be removed by evaporation and the overall effect is reduced drying time.

The large land areas required and the odor production potential of sand drying beds preclude their use in locales where land costs and population densities are high.

Frequently, sludges applied to drying beds are conditioned with chemicals or other materials.[10] An increased rate of drying is the major advantage sought in the use of conditioning aids. This advantage is very important when an inadequate drying area is available, when the sludge has poor drying characteristics, or when unfavorable weather threatens to delay the drying process. In addition to increasing dewatering rates, conditioning aids reduce sand bed maintenance requirements because uniform sludge drying throughout its depth permits more complete removal of cake from the sand. Materials used to condition sludges have included inorganic flocculents, polymeric flocculents, sawdust, sulfuric acid, anthracite, and activated carbon.[10]

Sand drying beds are extremely easy to operate. Basically, the beds are filled with sludge and left unattended until the sludge is dry. This is a major factor in the acceptance of drying beds by smaller communities where operating budget and operator expertise may be low.

General Assumptions

The technique of dewatering by using sand drying beds is basically limited to small communities where access to relatively inexpensive land areas exist. Open drying beds, unprotected from precipitation were assumed as the design basis. Typical solids loading rates for open sand drying beds of 10 to 25 lb/sq ft/year were assumed.[31] The acreage requirements on a square foot per capita basis is illustrated in Table B-6.

TABLE B-6

AREA REQUIRED FOR SLUDGE DRYING BEDS[31]

(Square feet per capita)

Type of Sludge	Open Beds
Primary digested	1.0-1.5
Primary and humus digested	1.25-1.75
Primary and activated digested	1.75-2.5
Primary and chemically precipitated digested	2.0-2.5

Capital costs and manpower requirements were obtained from Figures B-11 and B-12, respectively.

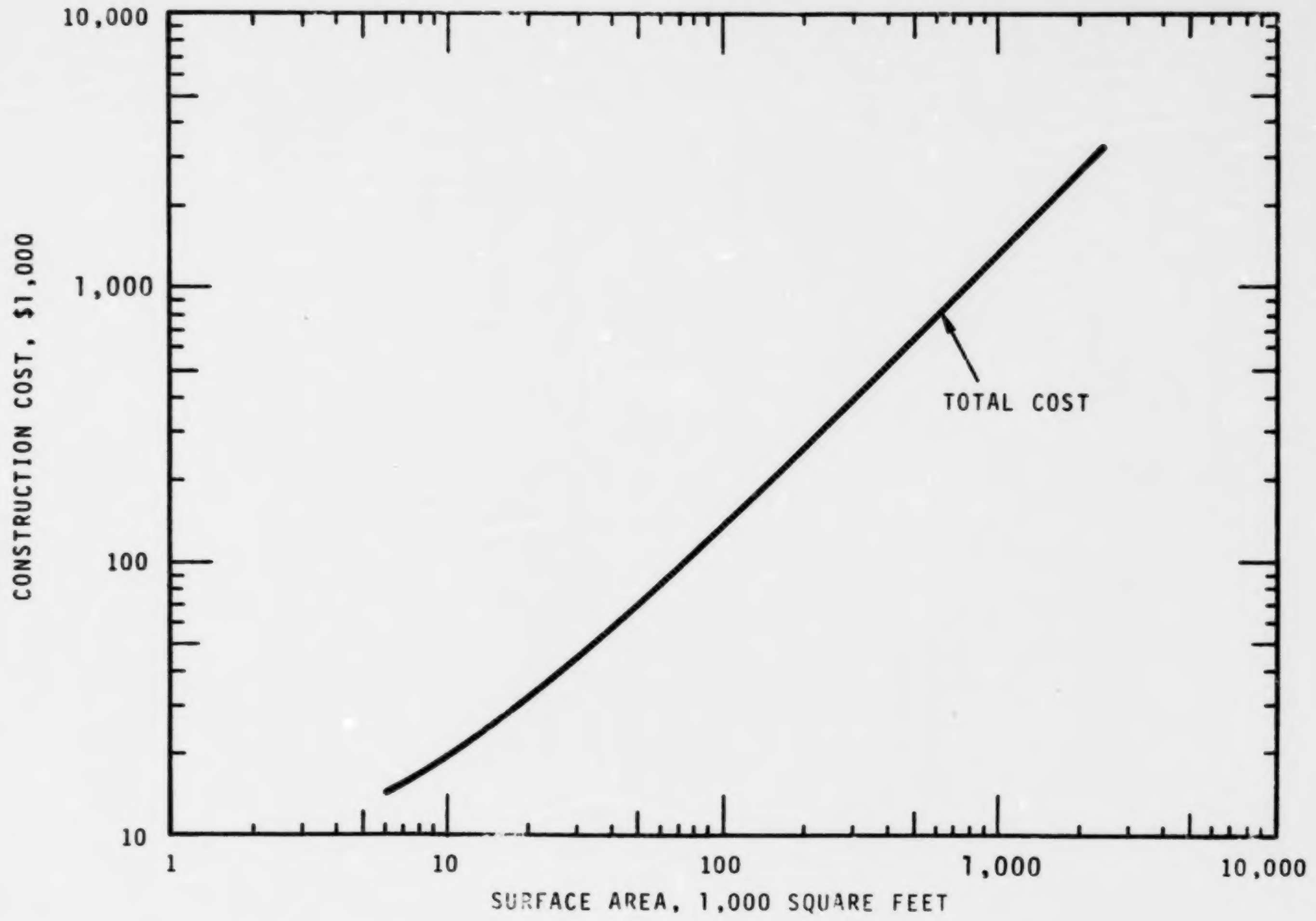

FIGURE B-11. SLUDGE DRYING BEDS, CONSTRUCTION COSTS[54]

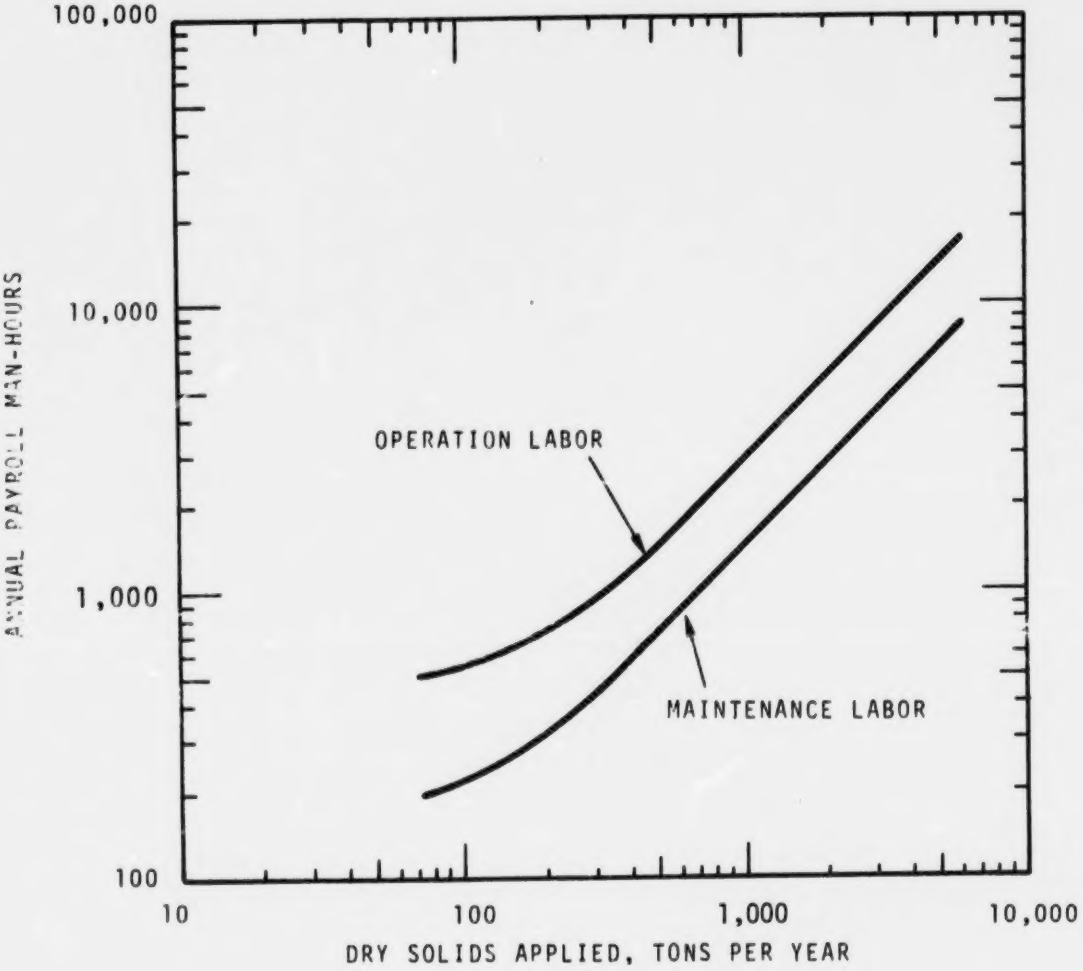

FIGURE B-12. SLUDGE DRYING BEDS, MAN-HOUR REQUIREMENTS[54]

VACUUM FILTRATION

Operation Description

Dewatering is a physical unit operation used to reduce the moisture content of sludge so that it can be handled and processed as a semisolid instead of a liquid.

Vacuum filtration is one of several means of mechanical dewatering preconditioned sludge and presently is the most widely utilized means of automated dewatering. Conditioning, as previously described, is a prerequisite for achieving acceptable and economical vacuum filtration dewatering. Conditioning coagulates the sludge allowing the water to drain out and, therefore, a thicker filter cake is produced which provides higher drum filter yields. Typical polymeric flocculant dosage levels for several sludge types are illustrated in Table B-7.[10]

The typical vacuum filtration mechanism involved consists of a sludge reservoir to act as a holding tank for the incoming sludge, a filter media (cloth or metallic) for sludge attachment, a revolving drum over which the media is stretched, a sludge cake scraper which removes the dewatered sludge from the media, a water spray for cleansing the media prior to sludge forming, various auxiliary equipment for delivery of the sludge to the filter, and piping to remove the filtrate. Figure B-13 depicts a typical vacuum filter flow diagram.

TABLE B-7

TYPICAL POLYMERIC FLOCCULENT DOSE LEVELS[10]

Type of Sludge	Polymer Dose Rate (% Dry Weight)
Raw primary or raw primary and filter humus	0.2-1.2
Digested primary	0.2-1.5
Digested primary and activated	0.5-2.0

The process involves submerging 20-40 percent of the drum surface in the sludge reservoir while a vacuum ranging from 10 to 26 inches of mercury is maintained inside the submerged portion of the drum. The vacuum drains the liquid into the drum, leaving the solids as a residue upon the filter media. As the drum

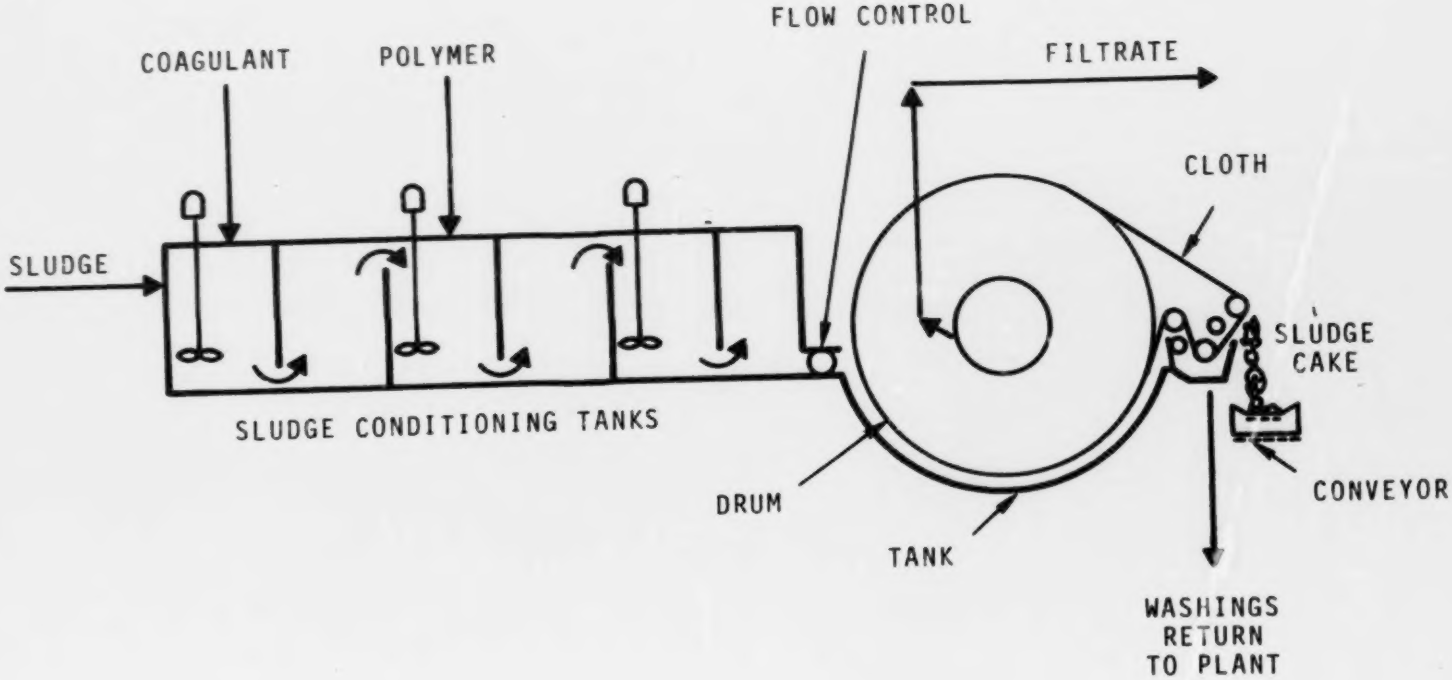
FLOW CONTROL
FILTRATE
COAGULANT
POLYMER
CLOTH
SLUDGE
SLUDGE CAKE
SLUDGE CONDITIONING TANKS
DRUM
CONVEYOR
TANK
WASHINGS RETURN TO PLANT

FIGURE B-13. VACUUM FILTER FLOW DIAGRAM[20] rotates, the cake grows in thickness and is lifted from the sludge reservoir. The continued maintenance of a partial vacuum upon the exposed filter media area allows for further drying by moisture removal and, possibly, by moisture transmission (mass transfer) to the air passing through the filter cake. Finally, the cake is removed from the filter before the media returns to the sludge reservoir by a stationary knife-blade scraper or by gravitational discharge.[53]

Most vacuum filter systems are designed based on data obtained from laboratory or pilot plant filter tests. Parameters of concern include sludge characteristics, filtration rates, cake moisture and number of filter operation cycles necessary.[10] An average conservative filter yield (defined as the number of pounds of sludge removed per square foot of filter media area per hour) of 4.0 lb/sq ft/hr can normally be assumed as an initial design parameter.[10] Typical yields obtained from raw and digested sludges are presented in Table B-8.

TABLE B-8

TYPICAL VACUUM FILTER PERFORMANCE[31]

Type of Sludge	Yield, lb/sq ft/hr
Fresh solids	
Primary	4-12
Primary + trickling filter	4-8
Primary + activated	4-5
Activated (alone)	2.5-3.5
Digested solids (with or without elutriation)	
Primary	4-8
Primary + trickling filter	4-5
Primary + activated	4-5

The number and size of filters necessary for a particular plant is based on the type of sludge to be filtered and the number of hours of operation. At small plants, 30 hours per week may be assumed, whereas at large plants, 20 hours per day may be necessary. The additional hours in the day are used for conditioning, clean-up, and possible operational delays. A plant may be designed for one shift operation initially, and for two to three shift operation of the same filters when the plant is expanded to provide for future or ultimate conditions.[31]

The quality of the filter cake is measured by its moisture content on a wet weight basis expressed as a percent. Filters are operated to obtain the maximum production consistent with the desired cake quality. Where the cake is to be heat dried or incinerated, the moisture content is a critical item, since all the water remaining in the cake must be evaporated to steam. If the cake is conveyed into a truck and hauled to a disposal site, moisture content is not as important, although it does affect the tonnage that must be hauled. In such cases, the drum can be operated at the highest speed that will produce a cake that will separate easily from the filter. Moisture content normally varies from 70 to 80 percent, but filters may be operated to produce a cake of 60 to 70 percent moisture when the cake is to be heat dried or incinerated.[31] Typical solids concentrations from vacuum filtration appear in Table B-9.

TABLE B-9

TYPICAL SOLIDS CONCENTRATIONS FROM VACUUM FILTRATION[10]

Type of Sludge	Feed Conc. (% Solids)	Cake Conc. (% Solids)
Raw primary or raw primary and filter humus	2.5-5.0	28-37
Digested primary	10-15	26-34
Digested primary and activated	4-6	24-32

Operational problems include media blinding caused by small size particles, non-uniform filter yields resulting from viscosity changes in the feed (possibly due to polymer application inconsistencies), and a tight filter cake resisting liquid separation due to an increase in sludge compressibility. Compressibility is normally proportional to the volatile content of the sludge.[10]

In addition to the preceding sludge quality parameters, vacuum filtration is sensitive to several physical parameters. Filter cake moisture and filter yield values are affected by drum speed and drum submergence. A cake possessing higher moisture content and an increased yield rate are obtained when the period of drum submergence is increased. On the other hand, decreasing the drum speed results in the opposite effect. Filter yield decreases and the moisture content of the sludge lowers.[20]

Recycling filtrate from the vacuum filter operation results in an additional suspended solids load to the plant. The suspended solids concentration in the filtrate varies from 100 to 20,000 mg/l depending upon sludge type, the degree and type of conditioning, type of filter media and the vacuum applied.[79] A buildup of fine solids may reduce overall plant efficiency when filtrate is returned to the influent of the treatment plant.[10] Thus, the plant design must consider the recycling of such material.

Vacuum filters provide the following advantages: (1) filters occupy a relatively small space, (2) various types of sludges can be dewatered, (3) the percent solids capture is high, and (4) the adaptability of the vacuum filter to various schedules improves the plant operational flexibility.[10]

On the other hand, vacuum filters can be odiferous, require highly trained operators, necessitate duplicate machines to prevent plant shutdown, and have high labor cost due to filter media blinding.

General Assumptions

Chemical conditioning was assumed to be a necessity for providing relatively high yields from vacuum filters. As was previously mentioned, the requirement for chemical additives and the dose level applied will be dependent on sludge characteristics and may fluctuate daily.

The maximum single unit size was assumed to be 500 square feet of filter surface area.

Six hours of productive filter operation was assumed for each eight hour work shift, leaving two hours for start-up and maintenance time.

Operation and maintenance costs were based on $2.7-$16 per ton of dry solids.[10] Capital costs included the costs for the installation of the vacuum filter, auxiliary equipment, and piping as well as a contingency for electrical wiring and ventilation (Figure B-14).

Manpower requirements were based on the data of Figure B-15.

INCINERATION

Operation Description

Incineration is practiced to reduce the overall weight and volume of the sludge and to sterilize the solids, thereby producing an odorless, inert residue that may be readily handled for ultimate disposal.

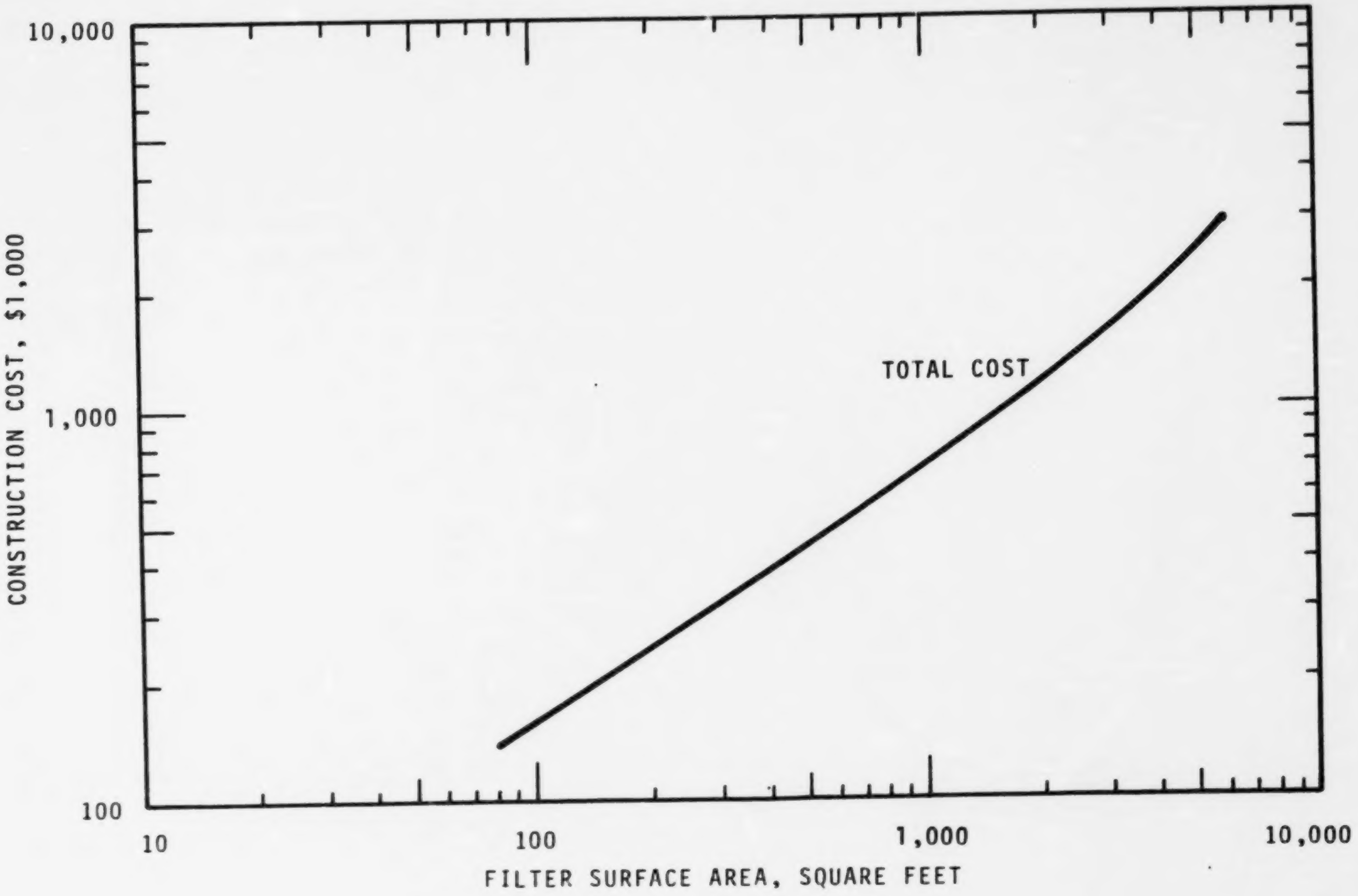

FIGURE B-14. VACUUM FILTRATION, CONSTRUCTION COSTS[54]

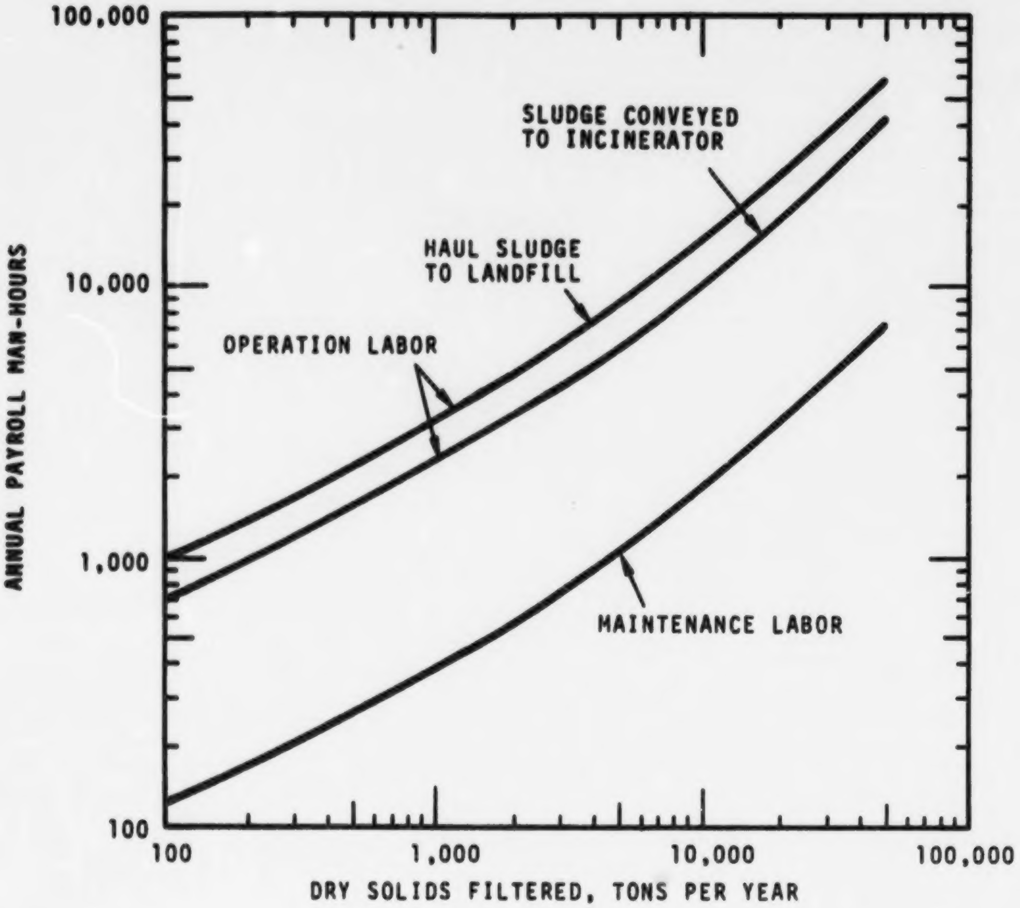

FIGURE B-15. VACUUM FILTRATION, MAN-HOUR REQUIREMENTS[54]

Several methods of sludge incineration exist including:

- Multiple Hearth
- Cyclonic Reactor
- Rotary Kiln
- Fluid Bed

The multiple hearth furnace consists of a circular steel shell with multiple refractory hearths as illustrated in Figure B-16. Air-cooled rabble arms are connected to a control shaft which rotates allowing the scrapers to move the sludge around the hearth dropping it to the next lower grate. This action exposes new surface areas to the hot gases and moves the sludge through the drying and burning stages.[53]

Burners are attached at specific locations in the shell of the incinerator to heat the furnace to the required temperature. A wet scrubber is normally attached to the stack gases to remove fly ash from the hot gases. The sterile, insoluble ash falls through a chute into a collection mechanism.[53]

In general, multiple hearth units are not heat efficient and are subject to high operating and maintenance costs. Rabble arm replacement is frequent due to wear and excessive heating of the tips. A wide range of unit sizes, from 500 to 2500 lb/hr dry solids are presently on the market.[4,27]

The cyclonic reactor is designed to provide incineration capabilities for small plants (less than 500 lb/hr). A preheated jet of air is introduced tangentially into a combustion chamber maintaining intensely heated surfaces. The sludge is sprayed radially toward the walls of the chamber and is essentially incinerated before reaching the refractory walls. The ash is transported by the exit flue gases. The total detention time is less than ten seconds and the operating temperature is approximately 1400°F.[27]

A rotary kiln incinerator, schematically illustrated in Figure B-17, consists of the sludge entering a rotating tumbler slanted at a 75 degree angle to allow the ash to collect at the far end of the furnace for disposal. The tumbler revolves at approximately 6 inches/second to expose fresh surfaces to the hot combustion gases. Hot combustion gases pass through a wet scrubber before they are released to the atmosphere.[27] The rotary kiln provides a wide range of operating capacities and has demonstrated low maintenance costs.

The fluid bed incinerator system is composed of a vertical refractory-lined cylinder, a burner in the side, and a wet

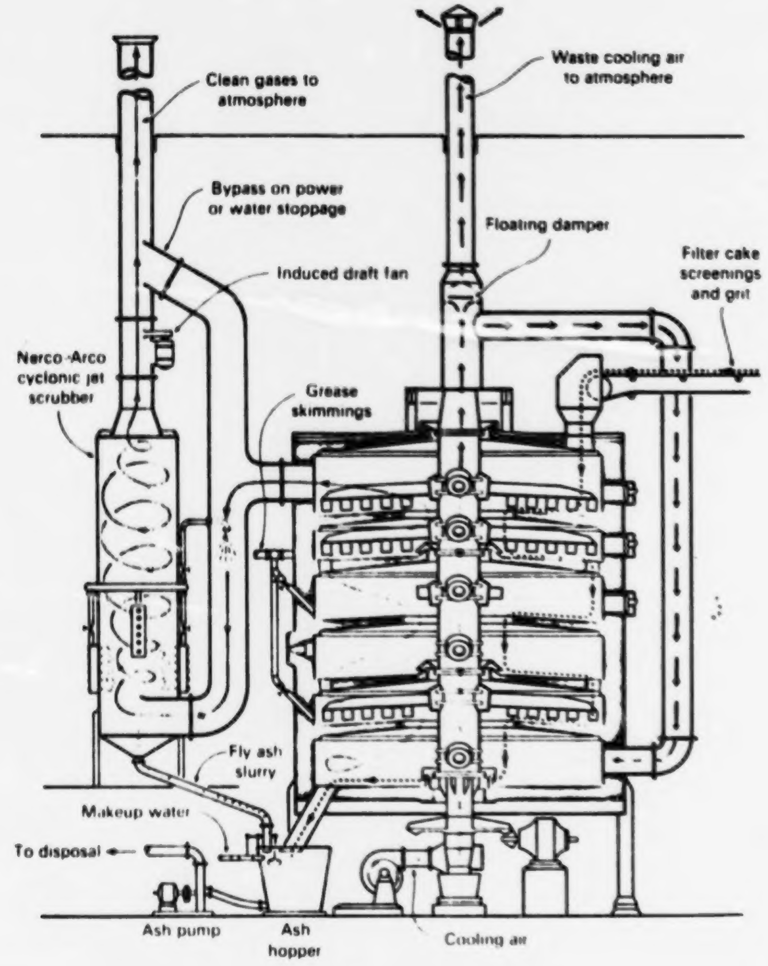
Clean gases to atmosphere
Waste cooling air to atmosphere
Bypass on power or water stoppage
Floating damper
Induced draft fan
Filter cake screenings and grit
Nerco-Arco cyclonic jet scrubber
Grease skimmings
Fly ash slurry
Makeup water
To disposal
Ash pump
Ash hopper
Cooling air

FIGURE B-16. MULTIPLE HEARTH INCINERATOR[10]

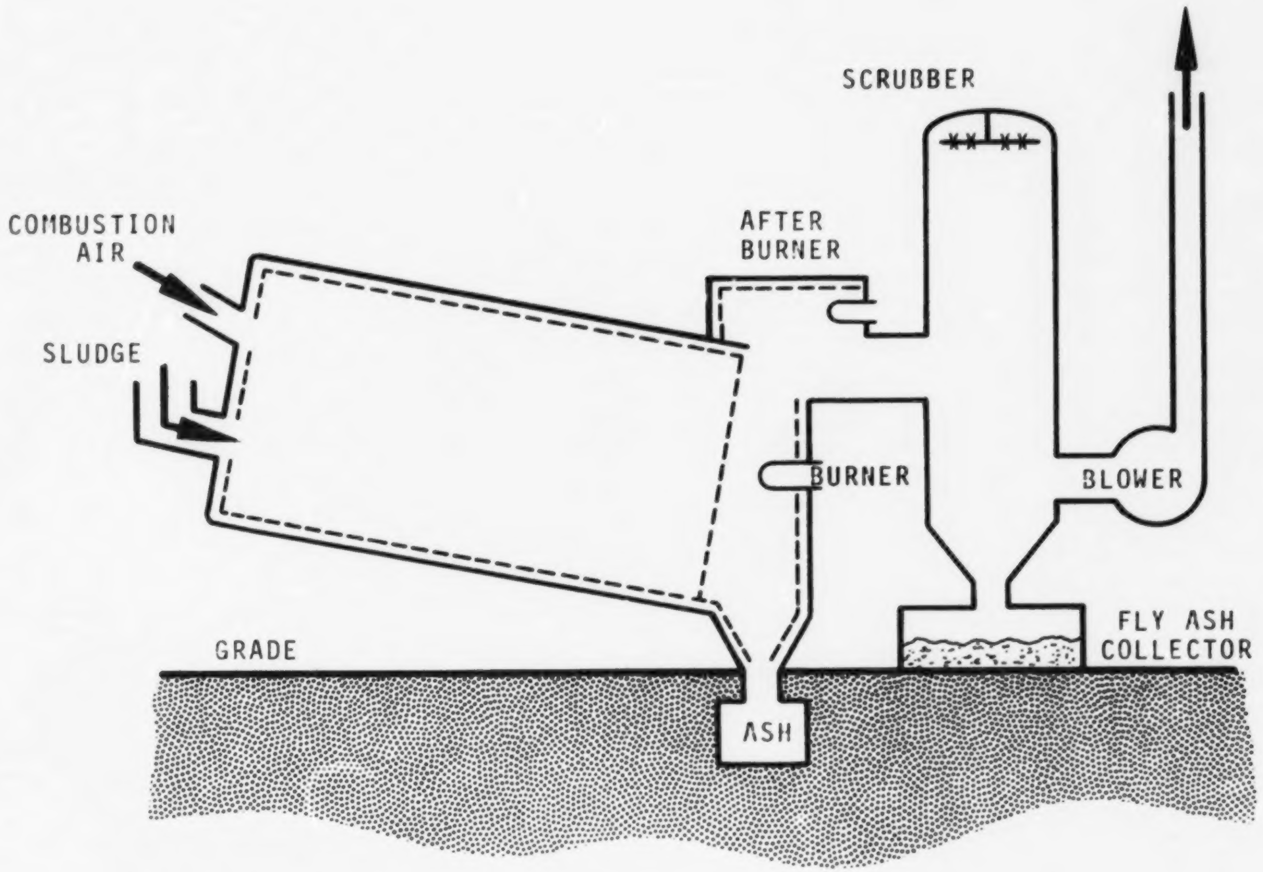
SCRUBBER
COMBUSTION AIR
AFTER BURNER
SLUDGE
BURNER
BLOWER
FLY ASH COLLECTOR
GRADE
ASH

FIGURE B-17. ROTARY KILN INCINERATOR[27] scrubber for flyash removal. The incinerator bed consists of gradiated silica sand which is heated by a preheat burner and fluidized by combustion air. The sludge is fed into the combustion chamber which is maintained at 1400-1600°F.[27]

The advantages of this particular system include:[27]

- no moving parts in the reactor;
- no heat exchange surfaces to scale;
- ash removal is by exit gases; and
- no odor control problems.

In general, the overall capital cost of this process is higher than the previous three processes.

The weight of the ash from the preceding processes is normally between 30 and 40 percent of the weight of the dry solids incinerated. Final disposal of ash is ordinarily accomplished at a sanitary landfill site.[10]

The heat value of the incoming sludge is one of the controlling factors influencing the total requirements for auxiliary fuel to aid in the combustion process. Typical sludge fuel values range between 4800 and 10,000 Btu/lb dry solids depending upon the characteristics of the sludge and the volatile content.[53] As the volatile content increases in the sludge, the amount of auxiliary fuel necessary to support combustion at temperatures above 1400°F decreases as illustrated in Figure B-18. Inorganic coagulation during the treatment processes increases the quantity of sludge produced but decreases the total fractional volatile content since the chemicals are inert. Furthermore, the presence of calcium carbonate will reduce the heating value since it decomposes endothermically to calcium oxide.[27]

The temperature necessary for complete, odorless combustion also affects the amount of auxiliary fuel necessary. Generally the minimum accepted temperature level for complete odorless combustion is 1400°F.[27] Figure B-19 illustrates the need for dewatering and preheating the incoming air in order to attain odorless combustion.

The solids content of the sludge must be in the range of 25 to 35 percent to sustain combustion in a multiple hearth or fluidized bed incinerator.[27] The amount of auxiliary fuel for sludges of varying moisture levels is presented in Figure B-20.

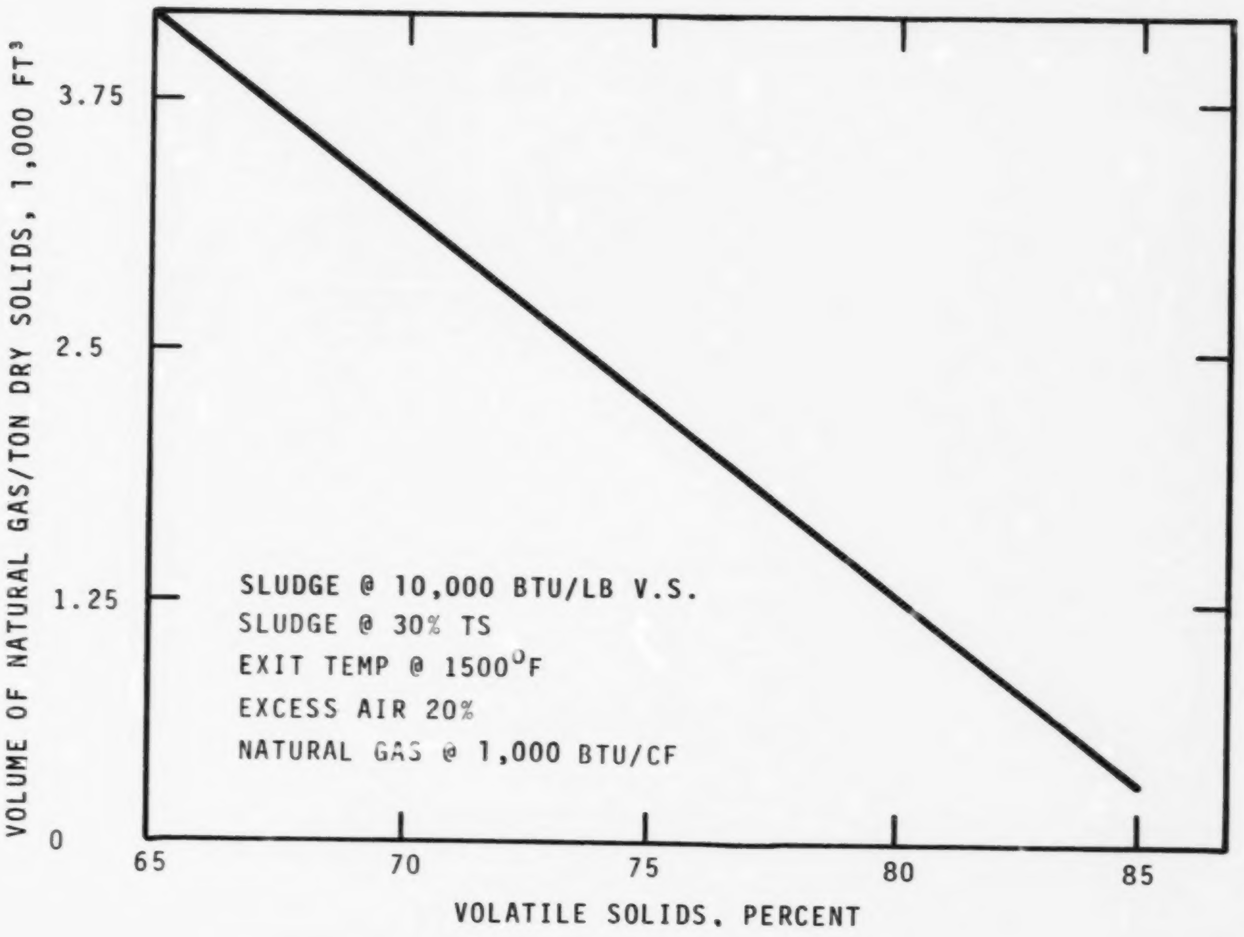

FIGURE B-18. EFFECT OF VOLATILES IN SLUDGE ON QUANTITY OF NATURAL GAS REQUIRED[27]

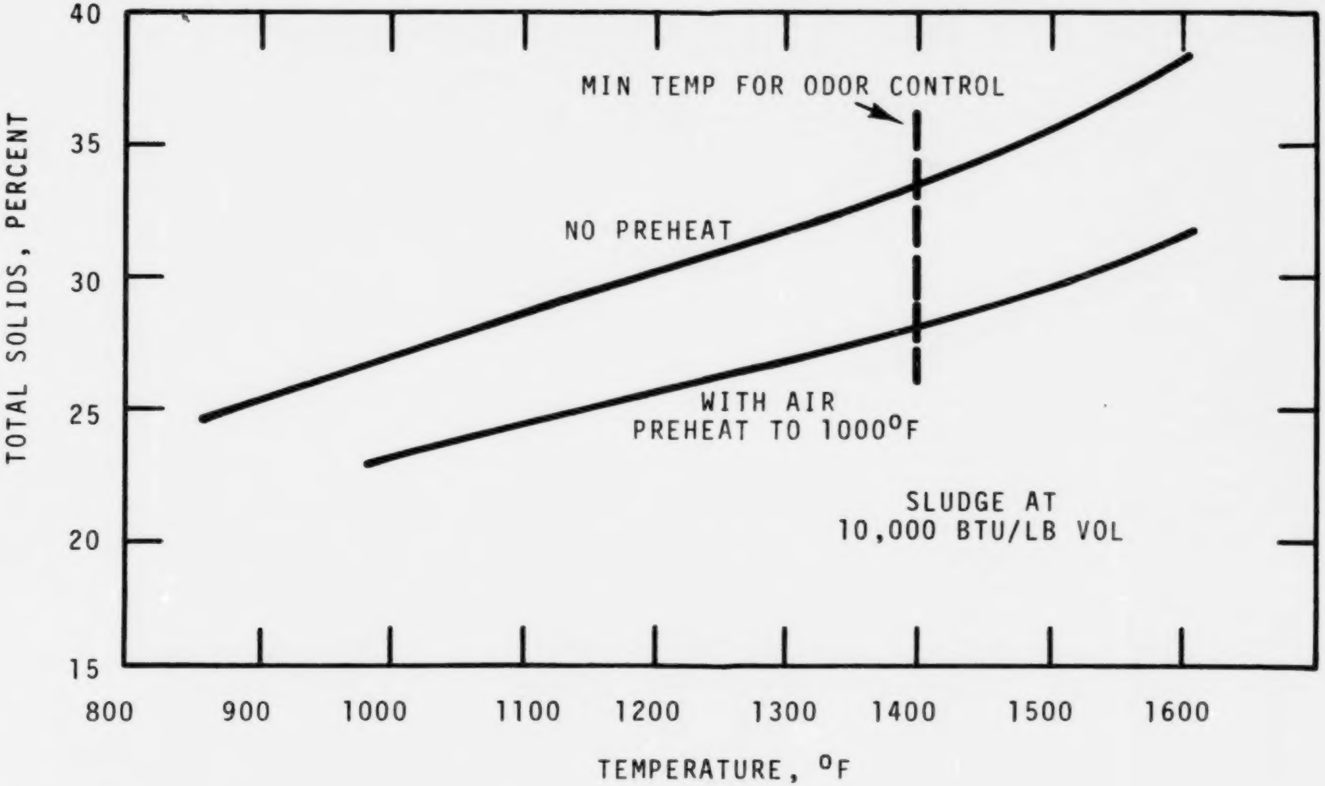

FIGURE B-19. EFFECT OF COMBUSTION TEMPERATURE VS THE PERCENT OF TOTAL SOLIDS[27]

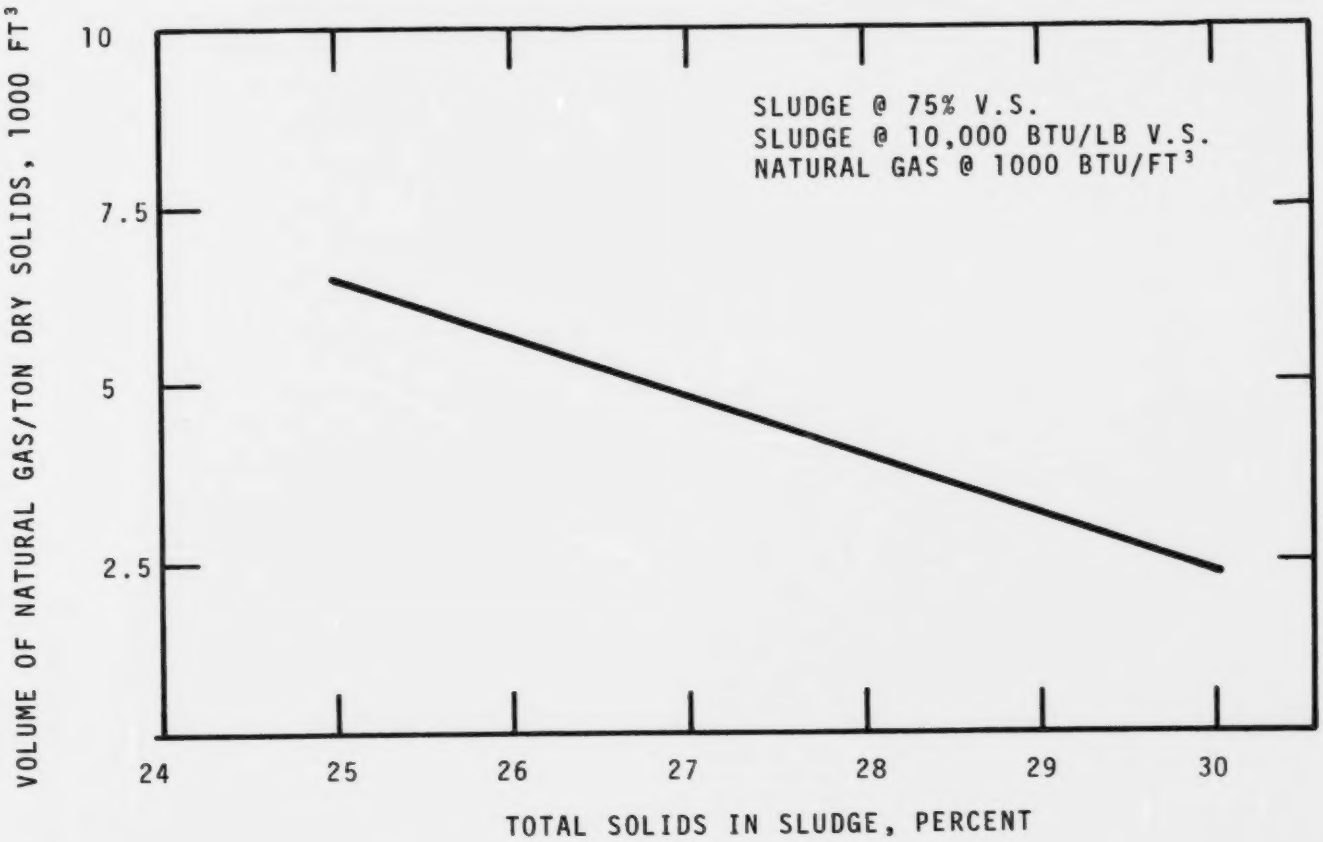

FIGURE B-20. PERCENT TOTAL SOLIDS VS AUXILIARY FUEL[27]

Furthermore, it is normally necessary to provide excess air over and above stoichiometric requirements for proper combustion.

General Assumptions

Sludge incinerator size is dependent upon the quantity of sludge produced, moisture level, volatile and inert solids contents of the sludge, heat value of the sludge, and operation schedule. However, except for quantity and operation schedule, the preceding parameters vary within limited ranges and can be represented by average values.[54] Hence, the incinerator size is in direct proportion to the rate (pounds of solids per hour) of incineration.

All incineration capital and operating costs, manpower and land requirements were based upon the installation of multiple hearth furnaces. For the middle range plants (between 10 MGD and 100 MGD), the preceding assumption is economically justified. However, for plants producing less than 500 lb/hour of sludge, the cyclonic reactor may be operationally more justified. (Assuming incineration of sludge for such a small operation is reasonable.)

For larger plants on the order of 1 BGD, it might be economically more appropriate to install large rotary kiln incinerators instead of numerous multiple hearth furnaces. Although the profile sheets reflect capital costs for multiple hearth units, a preliminary economic analysis indicates that substantial cost savings could be realized by substituting rotary kiln units for multiple hearth furnaces in installations substantially larger than 100 MGD.

The capital cost allowances presented include costs for a multiple hearth unit, auxiliary equipment, and an enclosing structure. Capital cost data was derived from the information presented in Figure B-21. Auxiliary equipment consists of a gas scrubber and exhaust, ash handling, fuel system, instrumentation, piping, and electrical facilities.[54] Labor requirements include removal of ash and proper care and repair of the incinerator system.

Gaseous and particulate emissions discharged from the incineration of wastewater sludge include nitrogen oxide, sulfur dioxide, water vapor, hydrogen chloride, heavy metals and other constituents.[57] The normal air pollution equipment provided with the incinerator is adequately efficient to meet EPA air pollution criteria.

Most incinerator systems include air pollution control mechanisms (e.g. wet scrubbers, cyclones,) as part of their standard design. It has been assumed for this study that the air pollution equipment supplied by the manufacturers will meet EPA standards and hence further equipment will not be necessary. Typical heavy

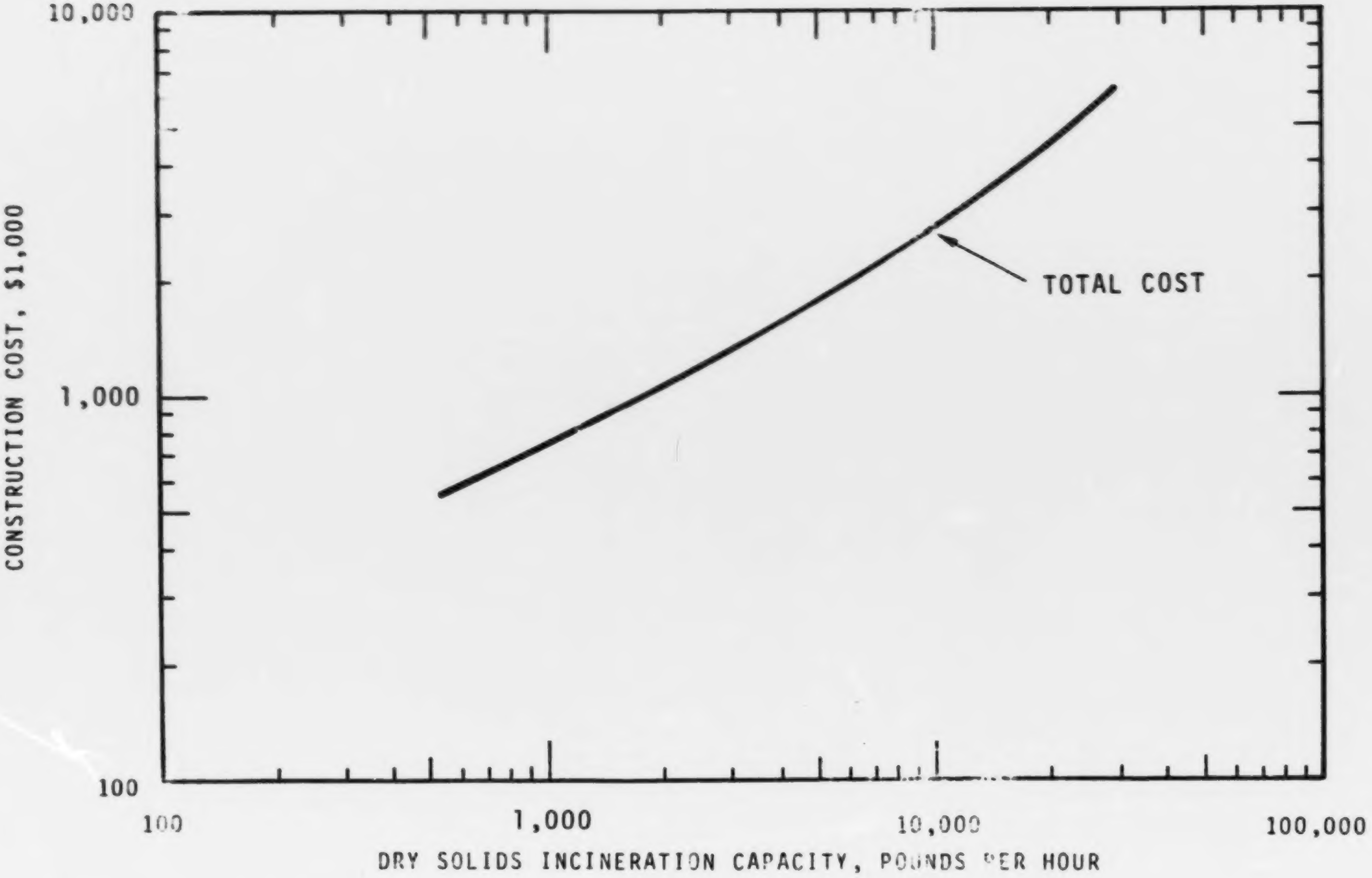

FIGURE B-21. MULTIPLE HEARTH INCINERATOR CONSTRUCTION COSTS[54] metal particulate emissions include silver, arsenic, cadmium copper, manganese, nickel, lead, vanadium, and zinc. Mercury is normally released in vapor forms, but the quantity produced during municipal sludge incineration is quite small. Most of the preceding metals will appear in the scrubber effluent or in dry form from precipitators.

Manpower requirements were based on data illustrated in Figure B-22.

RECALCINATION

Operation Description

Recalcination is the act of recovering calcium carbonate precipitate and burning it in the presence of oxygen to form CaO (lime) and carbon dioxide. The reclaiming of lime in large treatment facilities can be economical and eliminate the dependence of the plant upon a constant delivery of chemicals and possible shipment interruptions.

The sludge weight reduction through the incineration process was assumed to be only twenty percent and, in the case of recalcination, twenty-five percent of the recalcined lime was wasted in order to control the amount of phosphates and ash returned to the treatment plant system.[4]

For the 1 BGD plant, a substantial initial capital cost savings might be realized by the use of rotary kilns in the place of multiple hearths. The profile sheets indicate the cost of chemical sludge incineration and recalcination by multiple hearths. Should rotary kilns be substituted, on the 1 BGD level, a capital saving of $19-30 million for treatment strategies 8 and 9, and $37 million for treatment strategy 10 might be realized. Furthermore, the chemical sludges which were not recycled were mixed with the organic sludges and incinerated together in the multiple hearth units. Thus, maximum utilization of the incinerators was accomplished.

General Assumptions

The physical parameters and cost figures portrayed on the profile sheets for chemical sludge handling are based upon multiple hearth incinerators. Determination of the recalcination furnace size was based upon the same assumptions as the organic sludge incinerator. As was the case for organic sludge incinerators, recalcination furnace size is directly proportional to the pounds of solids applied to the incinerator per hour.

The capital costs and manpower requirements reflect the same basis as the organic sludge incineration option. Furthermore,

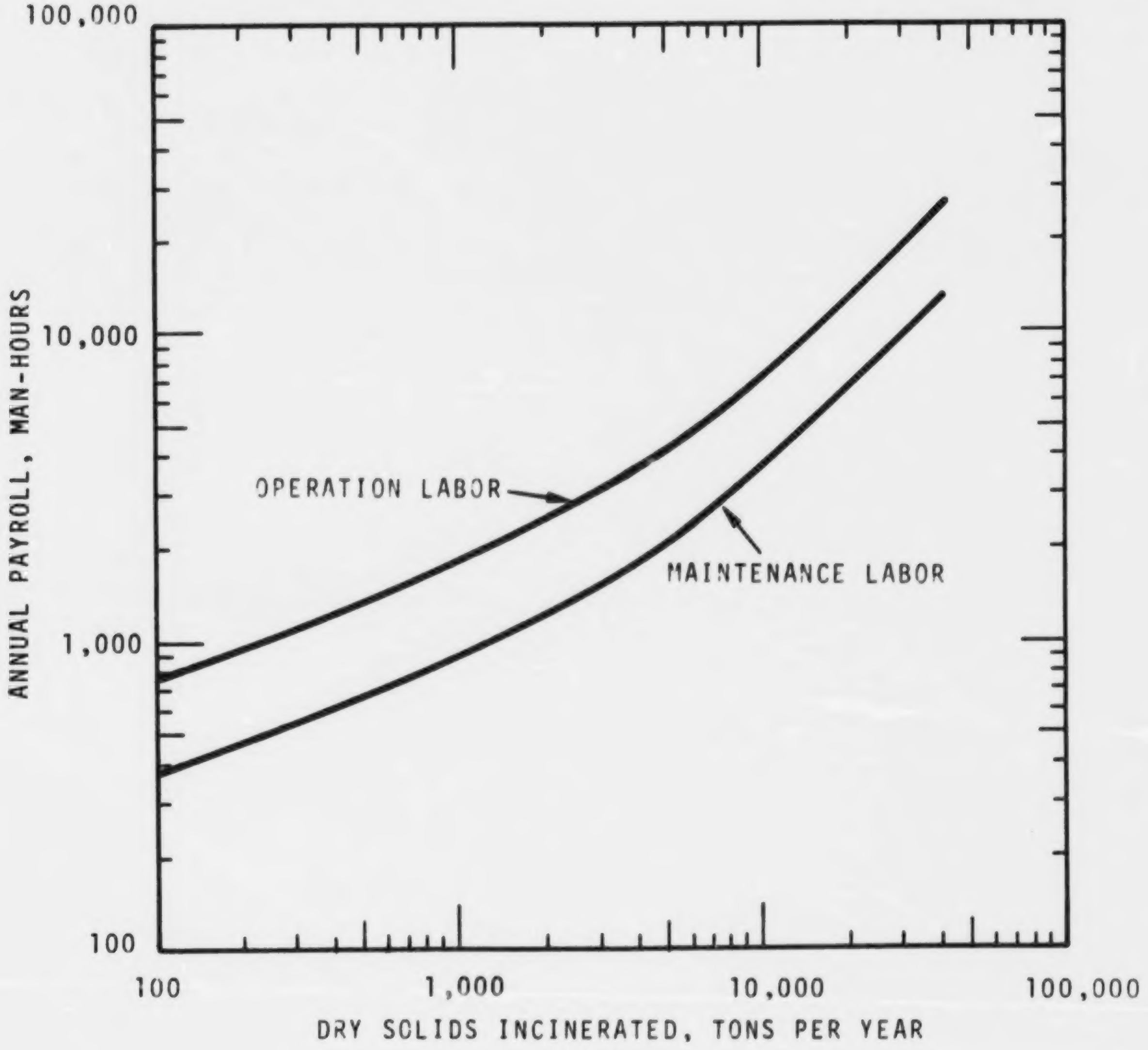

FIGURE B-22. INCINERATION, MAN-HOUR REQUIREMENTS[54] the actual capital costs and manpower figures were evaluated from Figures B-21 and B-22, respectively. Gaseous and particulate emissions were assumed not to exceed EPA air pollution criteria by the proper installation of pollution control equipment.

Recalcination furnaces differ from normal sludge incinerators only in operating temperatures and auxiliary equipment. Lime sludge, due to its high inorganic content ($CaCO_3$), requires higher operating temperatures, ranging up to 1900°F, for complete combustion.[4] Furthermore, the upper hearth on a multiple hearth unit must be maintained at a higher than normal temperature to prevent the formation of clinkers (the slow drying and agglomerating of the lime cake).

The recalcination furnace is usually followed by a lime grinder to break up large pieces of recalcined lime. The lime is then moved to a storage bin where 25-35 percent of the recalcined lime is wasted in order to minimize the amount of inert ash and phosphate being recycled to the plant.[4]

LAND DISPOSAL OF SEWAGE SLUDGES

Operation Description

Continuing efforts to reduce environmental degradation related to sludge disposal and increasing desire to gain more efficient use of resources has stimulated renewed interest in land disposal of sewage sludges. Advantages associated with this disposal technique include:[90]

- The process represents ultimate disposal because sludge is normally hauled off the treatment plant grounds by someone assuming responsibility for the material.
- The sludge has some value as a soil conditioner and fertilizer. (A discussion of this value is presented in Appendix C.)
- Small capital investment is required, particularly if a contract for hauling is negotiated.
- Sludge dewatering operations can be eliminated, thereby improving treatment plant economics and efficiency.

The major negative aspect of land disposal for liquid sludge is that it is not applicable to all waste treatment plants, mainly because acceptable disposal sites are not always conveniently available. Hauling to acceptable areas can be very expensive because of the large quantities of water associated with the sludge solids. Land disposal areas must be within a short hauling distance of the treatment plant if a pipeline is not available for sludge transportation. A discussion of the relation between land value and transportation costs is presented in Appendix C of this report. If the disposal site is not owned by the sludge discharger, the success of this technique depends on continued acceptance by the land owner and public health officials. A single application of odoriferous sludge could result in public opposition and potentially even litigation which could lead to denial of the disposal area to the discharger.

Digestion or some other form of stabilization of sewage sludge is a prerequisite to acceptable land disposal. This means of stabilizing sludge is costly and must be considered in an evaluation of alternative disposal methods. In addition to their sludge stabilization function, anaerobic digesters also provide storage capacity which is a provision for liquid sludge disposal systems due to inclement weather delay in tank-truck hauling to operations. The use of liquid sludge as a fertilizer or soil conditioner also involves public health aspects which must be considered when scheduling sludge applications on cropland. These issues are discussed in Appendix C.

Sludge is distributed on the land and processed in a variety of ways. Disposal at small plants may include simply the digging of shallow trenches, subsequent fill with liquid raw or digested sludge, and then covering with soil to prevent nuisance conditions. Sludge may be pumped or gravity fed through pipelines to agricultural fields or land to be reclaimed. At some orchards, the liquid sludge is injected into the subsoil under pressure. A very common technique is disposal of liquid digested sludge directly on the disposal site by spraying from tank trucks. Another technique for application on land is to spray the sludge from irrigation rain-guns.

Sewage sludge is a waste product that is well suited for land disposal; however, there are limits to the use of this means for ultimate disposal.[71] If the purpose of sludge spreading is disposal only, then protection of the soil is unimportant, and high application rates may be acceptable as long as water and air pollution, and nuisance conditions are avoided. Reclaiming unproductive soils may also permit great leeway with regard to application rates and accumulations of sludge. However, when the main objective of sludge spreading is to add fertilizer, water, and organic matter to cropland, or when crop byproduct values are important the operating options are more limited since the productivity of the soil and crops must be protected.

One of the greatest causes for public concern regarding sludge disposal on land is the uncertainty of the fate of pathogenic organisms and toxic substances, and the hazards to health which may attend such an operation. More information is needed about the occurrence and survival of various pathogenic organisms, transport of these agents through soil, and their occurrence in ground and surface waters. No incidence of disease is known to have been traced to sludge disposal operations, but this in part reflects a lack of any comprehensive studies in the area.[92]

Management of plant nutrients (principally nitrogen and phosphorus) added during sludge disposal on land must be considered. If the applied nutrients are greatly in excess of losses, concentrations reaching groundwater or surface streams may be excessive. High nitrate concentrations in drinking water are toxic to humans and to livestock. Nitrogen and phosphorus, transported from sludge spreading operations by erosion and leaching, contribute to eutrophication.

Another public health hazard that must be considered when sludges are to be used as fertilizers is heavy metals concentration. The variable and not insignificant concentration of heavy metals in sludges is shown in Table B-10.

TABLE B-10

HEAVY METAL CONTENT OF DIGESTED SLUDGE[201]

Heavy Metal	Stickney, IL (mg/l)	Calumet, IL (mg/l)	Toledo, OH (mg/l)
Aluminum	--	--	1800
Cadmium	9	1	--
Chromium	80	50	125
Lead	20	90	375
Manganese	5	13	300
Nickel	12	2	--
Zinc	150	90	500

Little is known of the fate of heavy metals in soil. Jenne[90] proposed that the principal factor in retention of the heavy metals is sorption on hydrous oxides of manganese and iron. It is expected, therefore, that there will be little migration in the soil. Nevertheless, the capacity of the soil to retain these elements must be limited and eventual heavy metal breakthrough to the groundwater must be considered when using sludge as a fertilizer. The possibility of surface water pollution by soil erosion or flooding of cropland must also be considered.

Heavy metal buildup in soils can be detrimental in two ways. Continued buildup in heavy concentration in the soil over long time periods can eventually sterilize soils and, thus, cancel the original intent of the sludge spreading operation. The other detrimental effect involves potential concentration of heavy metals in the tissue of plants grown on land which has been subjected to sludge spreading. Public health hazards could result directly from ingestion of vegetables, fruits, or grains grown on this land or indirectly from ingestion of meat from animals which have grazed on the land. Further research is needed concerning the toxicity of heavy metals to plants and on the human and livestock intake through the food chain resulting from concentration of heavy metals in plant tissues.[92] Methods of treatment for heavy metals removal may need to be developed.

Great concern has been expressed by the general public for nuisances which might arise from land disposal operations. Odors, flies, and aesthetic degradation of the neighborhood seem to be the most common complaints. These problems should not arise in a well operated and managed sludge spreading operation.

Fly breeding problems can be minimized by allowing the site to dry well between sludge applications and by judicious use of insecticides.

Malodors can be prevented by application of well digested sludge at rates which allow site drying to proceed rapidly.

Concern for impairment of the aesthetic environment are probably exagerated. Experience has shown this to be no real problem. Care must be taken to keep the area neat, to keep weeds out, to maintain physical improvements, fences, and buildings in good repair, to guard against spillage of sludge by trucks along the roadway to the site, to prevent overflow of sludge from plots to ditches in the area, and to keep the public fully informed of the nature of the operation. These are simply good management practices in any waste-treatment operation, and land-disposal operations should present no more of a problem than waste treatment plants.

General Assumptions

Digested sludge for landspreading can be transported by truck, rail or pipeline. Truck transportation has been assumed to service plants of 10 MGD or less and pipelines assumed adequate for plants of 100 MGD or greater. Round trip hauling distances of 20 miles were assumed for plants of 1 MGD or less and 50 miles for plants larger than 1 MGD. Furthermore, it was assumed that the hauling contract included the costs of operation, maintenance and fixed charges for storage and loading facilities as well as the actual costs of transportation.[72] The cost curves illustrating the truck hauling expenses for 1.0 and 10 MGD plants are shown in Figures B-23 and B-24.

The pipeline mode of transportation consisted of a total length of 50 miles, 25 miles through a suburban area and 25 miles through rural land. Capital costs included pipe fittings, installed pump stations, right of way, and control instruments. They do not include the cost of land. Figures B-25 and B-26 illustrate the cost curves utilized. The operating costs included power, labor, supplies, and maintenance and these costs are reflected in Figure B-27. The piped and trucked slurry was assumed to have a 4 to 8 percent solids concentration.

The actual application of the sludge was assumed to be by the use of a rain gun at an average cost of $10/day ton.

The loading capacity for landspreading of the liquid sludge in order to prevent over utilization and saturation of the soil, was assumed to range between 10 and 40 dry tons/acre/year.

OCEAN DISPOSAL

Operation Description

Ocean disposal by pipeline or barging is a popular means of ultimate disposal of sludges for relatively large communities located near, or having easy access to, the sea.

Disposal by barging normally requires the installation of holding tanks to store the sludge prior to pumping into the barge. Depending upon the size of the installation, the barge will either be leased or owned by the municipality. Dewatering is a prerequisite in order to minimize the volume and tonnage which must be hauled.

Pipeline disposal is relatively capital intensive and because of the high initial cost, its use is restricted to rather large installations (greater than 100 MGD). Furthermore, the required length, special pipelining and ballasting, sludge pumping characteristics (specifically solids concentration), and location all affect the overall cost of the installation.

Recent EPA regulations require digestion of municipal waste sludge before disposal to the ocean. The intent of these regulations is to minimize bacterial contamination of the oceans. Indications from EPA are that more stringent regulations on ocean disposal may be forthcoming.

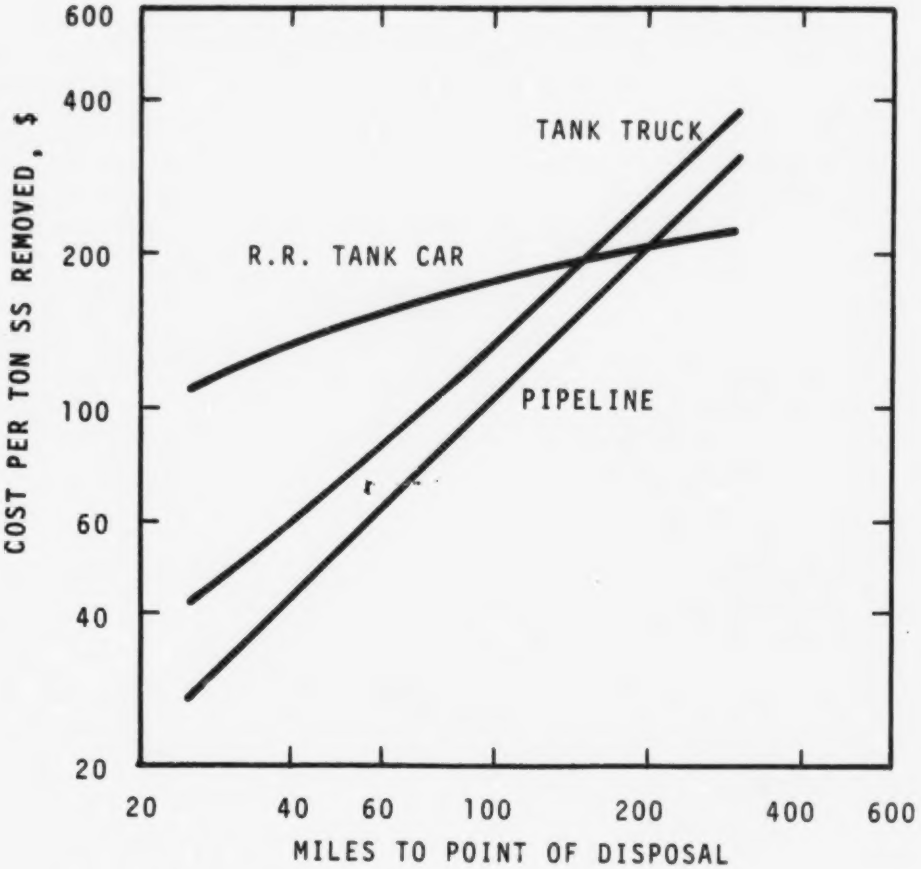

FIGURE B-23. TRANSPORTATION COSTS FOR A FACILITY SERVING A POPULATION OF 100,000[72] (FLOW EQUIVALENT, 10 MGD)

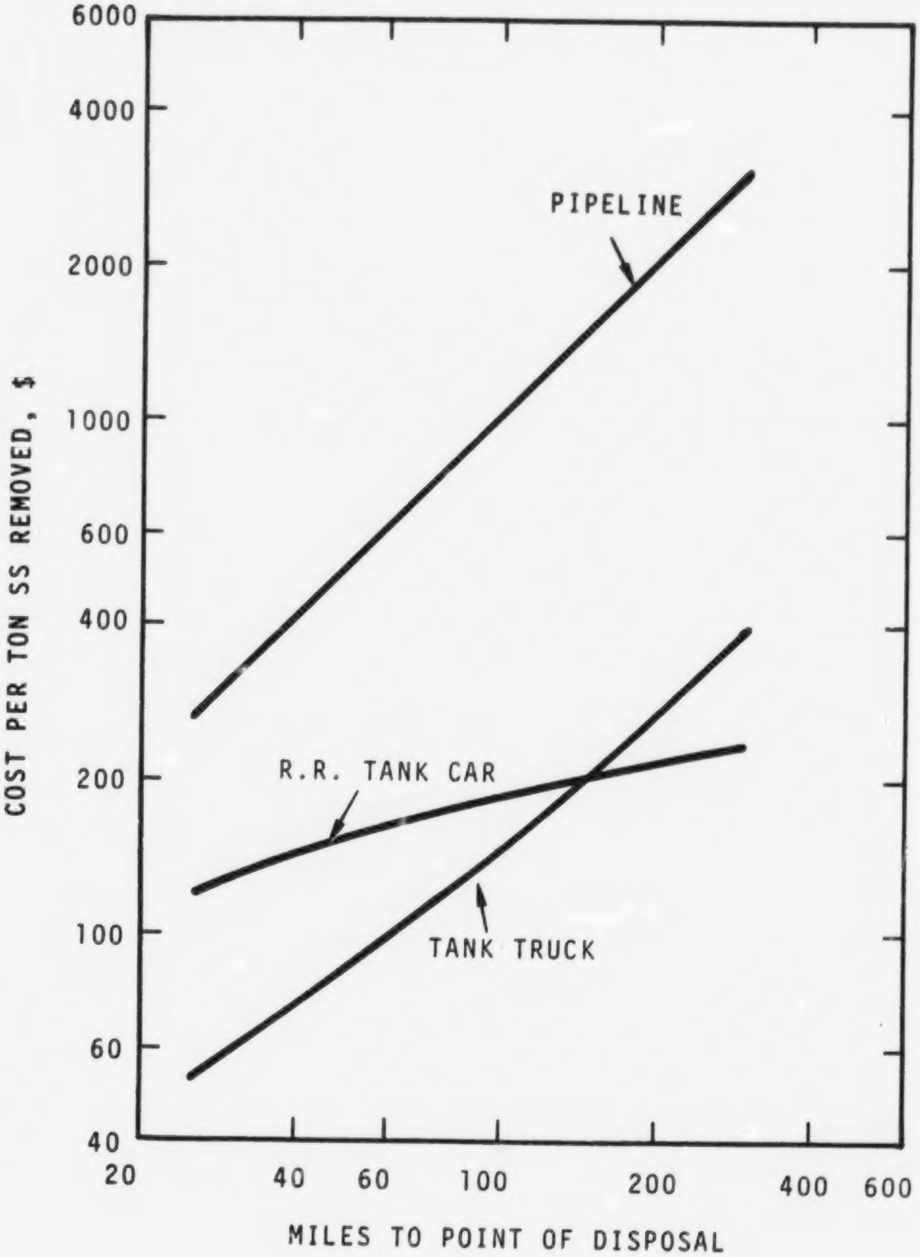

FIGURE B-24. TRANSPORTATION COSTS FOR A FACILITY SERVING A POPULATION OF 10,000[72] (FLOW EQUIVALENT, 1 MGD)

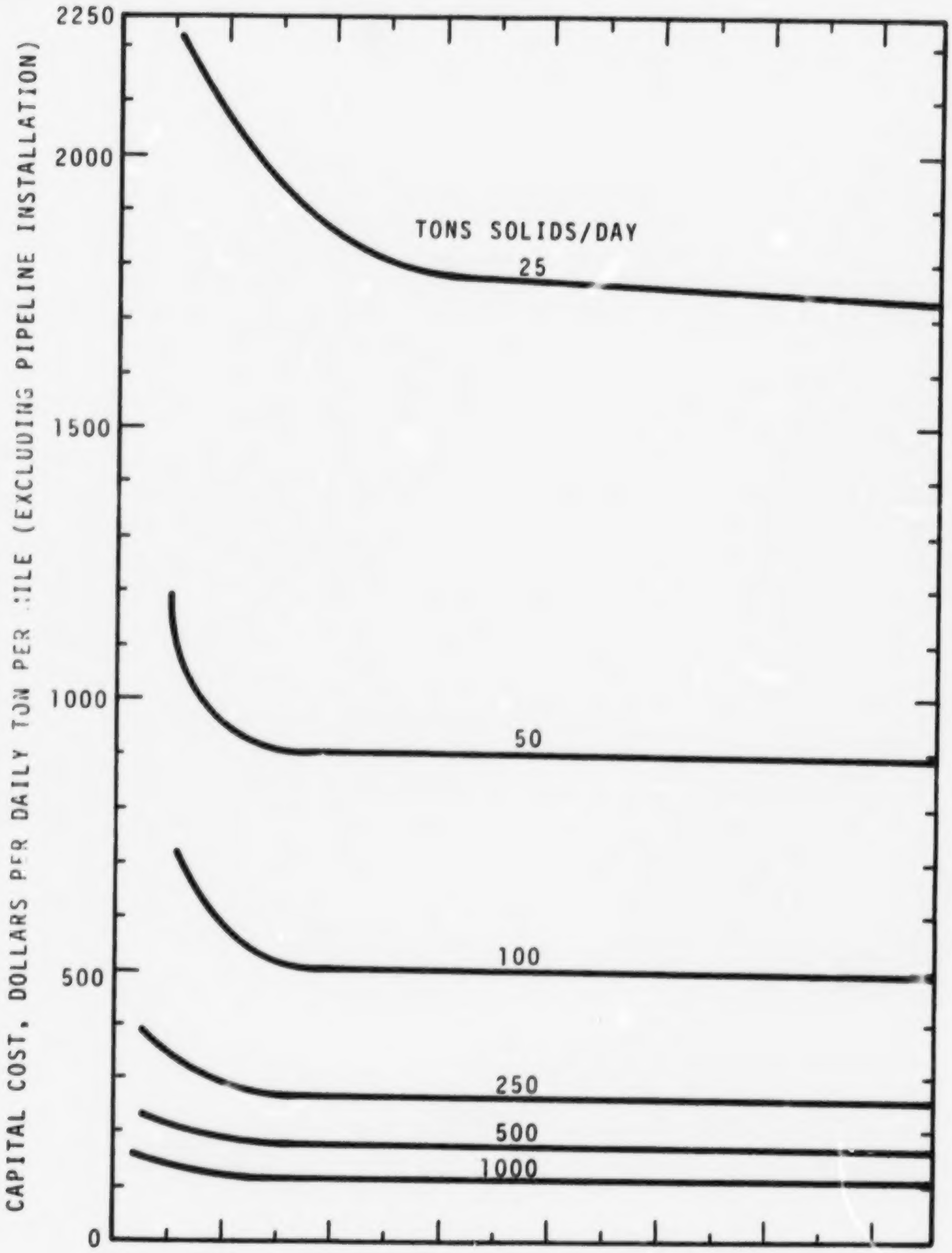

FIGURE B-25. CAPITAL COSTS (EXCLUDING INSTALLATION) VS DISTANCE FOR VARIOUS DIGESTED SLUDGE THROUGHPUT LEVELS[68]

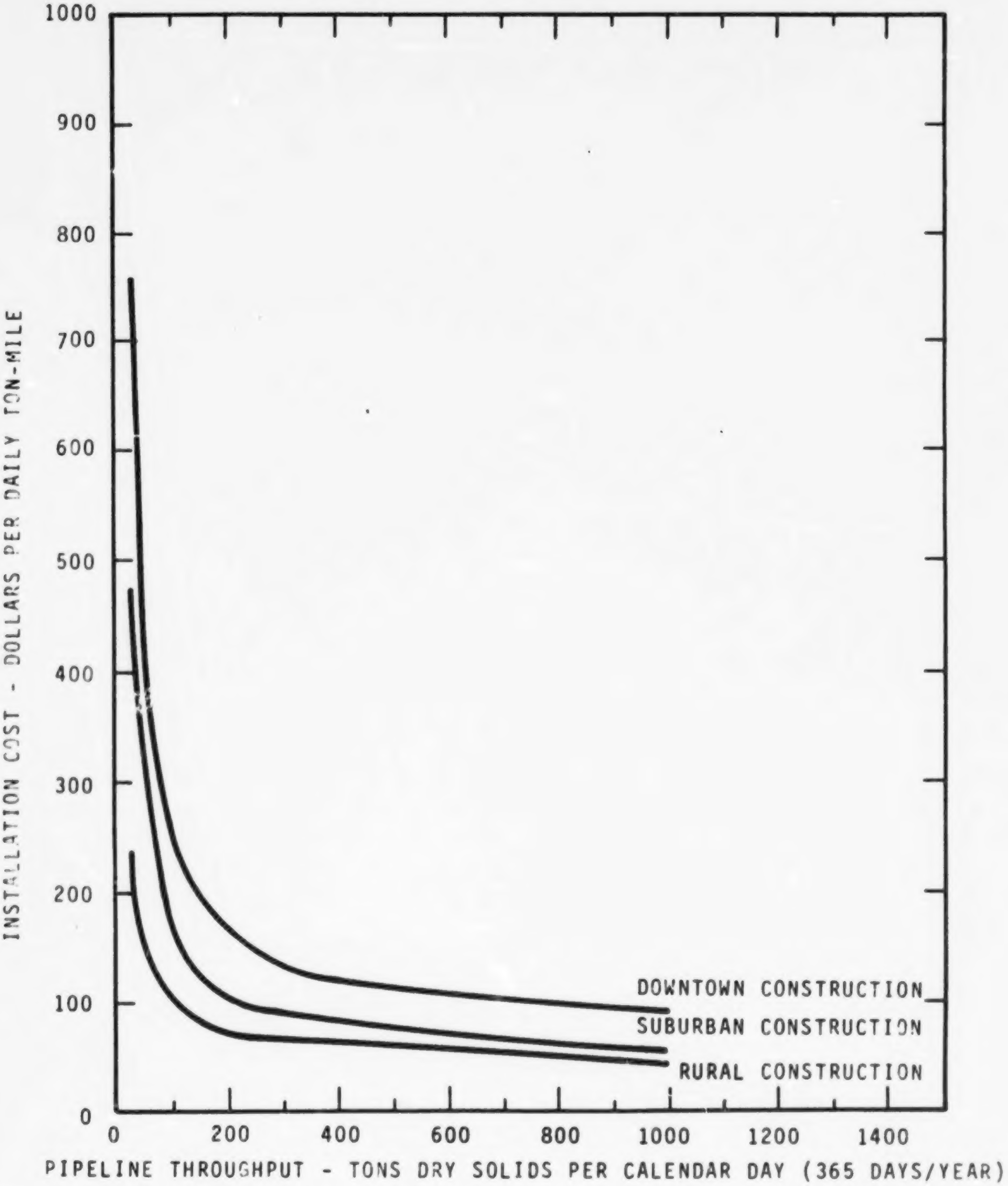

FIGURE B-26. PIPELINE INSTALLATION COSTS VS CAPACITY FOR THREE CONSTRUCTION ZONES[68]

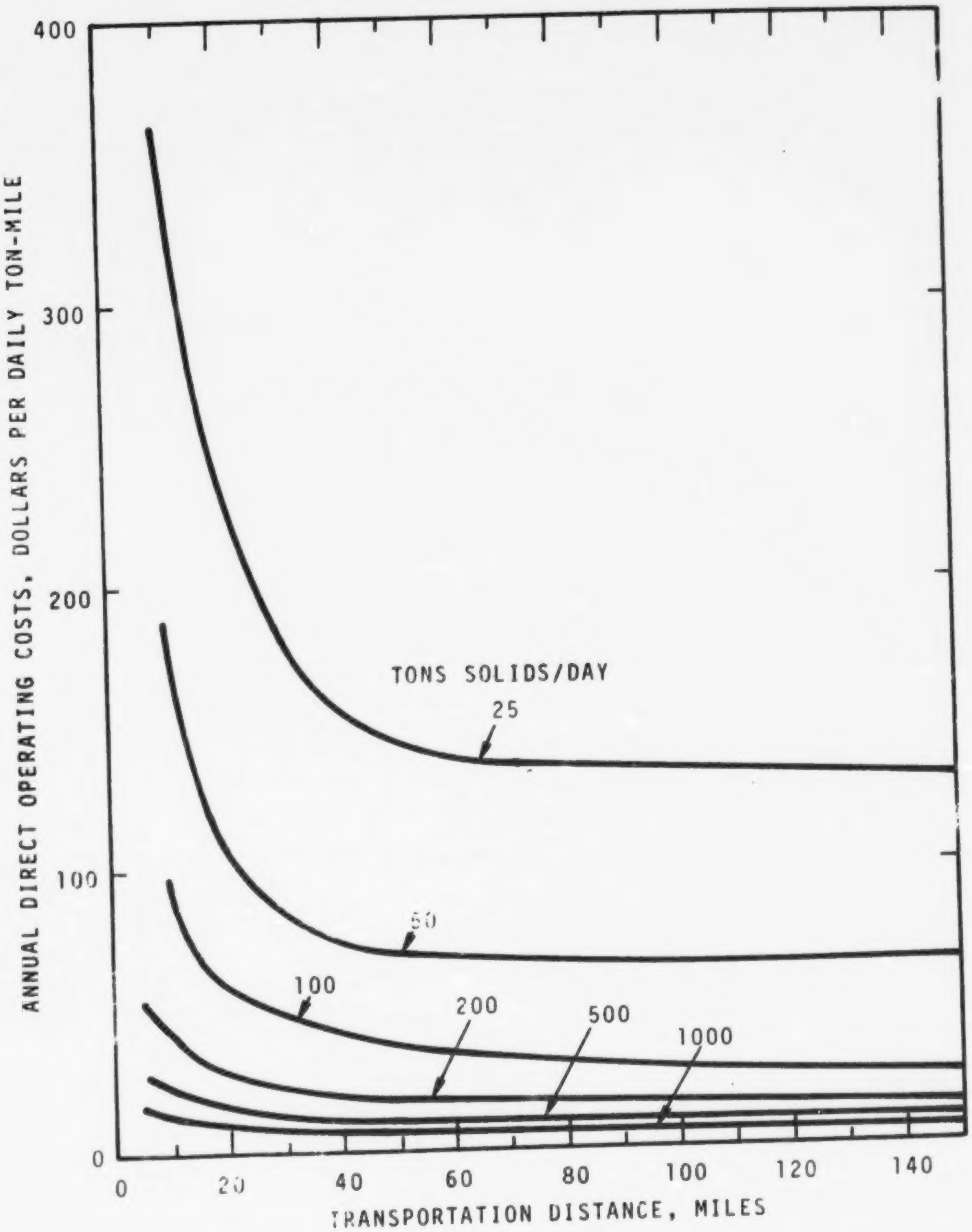

FIGURE B-27. DIRECT OPERATING COSTS VS DISTANCE FOR VARIOUS DIGESTED SLUDGE THROUGHPUT LEVELS[68]

General Assumptions

For volume reduction purposes, all barged sludges were initially dewatered. Sludges transported by pipeline were assumed to have a 4 to 8 percent solids content to minimize frictional head loss. Due to the capital intensiveness of ocean pipelines, their use was restricted to plant sizes on the order of 100 MGD or larger. Ocean barging of sludges was restricted to plant sizes of 1 to 10 MGD.

Barging costs were based on the need for two barges with the community owning the barges and contracting for tug service. The second barge acted as a substitute and both barges were assumed to have a capacity of 1000 tons. An average hauling distance of 50 miles at a speed of six knots with a towing cost of $88/hour was assumed.[67] Operating costs included maintenance, labor and towing costs.

The ocean pipeline was considered to pass through five miles of rural land and to extend eighty miles beyond the shoreline.

Capital investment included pipe fittings, installation, right of way and instruments and control.[68] Operating costs were comprised of power, labor, supplies, and maintenance.

SANITARY LANDFILL

Operation Description

A sanitary landfill can be used for disposal of sewage sludge and municipal refuse if a suitable site is convenient. When operated properly, such a landfill is a well-controlled and truly sanitary method of disposal of solid waste and dewatered sewage sludge. It consists of four basic operations:[70]

- wastes are deposited in a controlled manner in a prepared portion of the site;
- the wastes are spread and compacted in thin layers;
- the wastes are covered daily or more frequently, if necessary, with a layer of earth; and
- the cover material is compacted daily.

When the site is filled, the resulting land area can be developed for some other purpose where gradual subsidence would not be objectional such as a gold course, tennis court, playfield, botanical garden, or municipal riding ring.

An important step toward establishing an acceptable sanitary landfill operation is site selection. Proper site selection can eliminate many future operational problems. Well qualified and experienced experts should be utilized during the site selection phase of project development. Some of the major factors which should be considered in site selection are:

- land requirements,
- waste haul distance,
- cover material,
- geology, and
- climate.

The land area, or more precisely, the volume of fill space required, is primarily dependent upon the quality and quantity of the solid wastes (and/or sludges), the efficiency of compaction of the wastes, the depth of the fill and the desired life of the landfill.

The volume requirement for a sanitary landfill should be determined from specific data and information for each individual project.

Haul distance is an important economic factor in selecting the sanitary landfill site. The most economical distance to the site will vary from locality to locality depending upon capacity of collection vehicles, hauling time, and size and method used in the collection operation. The larger the quantity of refuse hauled per trip and the shorter the hauling time due to good roads, the greater the distance the wastes can be hauled for the same cost.

The availability of cover material is another economic factor to consider, for the cost of hauling cover material to the site can be excessive. A site that has cover material close by will keep these costs at a minimum.

Field investigations of potential sites should include soil analyses to determine the suitability and the quantity of soil available for cover material. Soil with good workability and compaction characteristics is the most desirable cover material.

The potential danger of ground and surface water pollution cannot be overlooked. Solid wastes, especially sewage sludges, ordinarily contain contaminents and infectious materials. Serious public health problems can result if pollutants enter water supplies. Site selection should include a geological investigation of the site to determine the potential for either surface water or groundwater pollution. The groundwater situation at a possible site should be examined for groundwater table elevation, historical high groundwater level, and the general movement of the groundwater.

Geological investigation should also examine the topography of the site and surrounding area to determine flooding potential during heavy rainfalls and snow melts. Site drainage must also be considered since surface water drainage and flooding can quickly erode the cover material and the refuse fill.

Sites located near rivers, streams, or lakes also deserve careful scrutiny. Normally, a landfill should not be located in a flood plain because of the water pollution hazard, and because these sites can become unstable both during and after floods.

In some locations, climate is important in site selection and may even dictate the method of operation. In an extremely cold locality, a site requiring excavation of trenches and cover material may become a problem if the ground freezes during the winter months. This problem can be eliminated if enough trenches and cover material are excavated during the summer to carry the operation through the winter period.

In areas of high rainfall, a low-lying site may be undesirable because of flooding and muddy working conditions. In such locales, a site elevated in relation to the surrounding area having good drainage features would be desirable.

Other factors which must be considered in site selection are 1) zoning restrictions, 2) accessibility, and 3) fire control facilities.

Sanitary landfilling consists of the basic operations of spreading, compacting, and covering. The three basic methods used to achieve the desired results are the area method, the trench method, and the ramp or slope method.

In an area sanitary landfill, the solid wastes are placed on the land; a bulldozer or similar piece of equipment spreads and compacts the wastes; then the wastes are covered with a layer of earth; and finally, the earth cover is compacted. The area method is best suited for flat areas or gently sloping land, and is also used in quarries, ravines, valleys, or where other suitable land depressions exist. Normally the earth cover material is hauled in or obtained from adjacent areas.

In a trench sanitary landfill, a trench is cut in the ground and the waste material is then spread in thin layers in the trench and covered with earth previously excavated from the trench. The trench method is best suited for flat land where the water table is not near the ground surface. Normally the material excavated from the trench can be used for cover with a minimum of hauling. A disadvantage is that more than one piece of equipment may be necessary.

In the ramp or slope method, the solid wastes are dumped on the side of an existing slope. After spreading the material in thick layers on the slope, bulldozing equipment is used for compaction of the waste. The cover material, usually obtained just ahead of the working face, is spread on the ramp and compacted. This landfill method is generally suited to the greatest variety of site topography. The advantage of utilizing only one piece of equipment to perform all operations makes the ramp or slope method particularly applicable to smaller operations.

Important factors in the operation of a sanitary landfill are waste compaction, cell depth, and the cover material.

Solid wastes should be placed at the top or base of the working face, spread in layers about two feet thick, and compacted. The degree of compaction is dependent on the character of the solid wastes, the weight and type of compacting equipment, and the number of passes the equipment makes over the material. The actual density of the landfill can be determined from operating records and data. The degree of compaction is a useful tool to determine the rate of space usage, expected life of the landfill, and the overall efficiency of the operation.

Cell depth is the thickness of the solid waste layer measured perpendicular to the working slope where the equipment travels. The depth of cells is determined largely by the size of the operation, the desired surface elevation when the site is filled to capacity, the depth of the trench or depression to be filled, and the amount of available fill material. Eight feet is generally recommended as a maximum single cell depth because deeper cells usually result in fills that have excessive settlement and surface cracking due to biological degradation and shifting of the waste material in the cell. However, cell depths of sanitary landfills presently in use vary from 2 to 15 feet or more.[70]

The compacted solid waste must be covered at the conclusion of each day, or more frequently if necessary, with a minimum of six inches of compacted earth.[70] A well-graded soil having good workability and compaction characteristics is a most desirable cover material. If a well-graded soil is not available on the site, it will be necessary to adjust the covering procedures to the type of cover material available or to haul in a suitable cover material. The cover is necessary to prevent insect and rodent infestation, blowing papers, fires, the attraction of wildlife, and the release of gas and odors.

For daily cover, a minimum of six inches of compacted soil is recommended. For intermediate cover on cells which will not have additional cells placed on them within a year, a minimum of twelve inches of compacted soil is recommended. A minimum of two feet of compacted soil is recommended for the final cover. The final cover should be placed over the fill as soon as possible to help assure that wind and water erosion does not expose the wastes.

The most common equipment used on sanitary landfills is the crawler or rubber-tired tractor. The tractor can be used with a dozer blade, trash blade, or front-end loader. A tractor is versatile and can normally perform all the operations: spreading, compacting, covering, trenching, and even hauling the cover material.

Other equipment used on sanitary landfills are scrapers, compactors, draglines, and graders. These types of equipment are usually found only at large sanitary landfills where specialized equipment increases the overall efficiency. In Table B-11, a general guide is given for the selection of the type, size, and amount of equipment for various sizes of sanitary landfills.

Important public health and nuisance aspects which must be considered in landfill operation are 1) vector control, 2) water pollution, 3) odors, and 4) gas production.

In a properly operated and maintained sanitary landfill, insects and rodents are not a problem. Well-compacted wastes and cover material are the most important factors in achieving vector control.

Proper planning and site selection, combined with good engineering design and operation of the landfill, can normally eliminate the possibility of either surface or groundwater pollution. Some common preventive measures are:

- Locating the site at a safe distance from streams, lakes, wells, and other water sources;
- Avoiding site location above the kind of subsurface stratification that will lead the leachate from the landfill to water sources;
- Providing suitable drainage trenches to carry the surface water away from the site.

Odors are usually the result of gases from anaerobic decomposition of putrescible material such as raw sewage sludge. These are generally considered a nuisance but can be a public hazard. The odors are characteristic of hydrogen sulfide gas produced in

TABLE B-11

AVERAGE EQUIPMENT REQUIREMENTS[70]

Population	Daily Tonnage	No.	Equipment		
			Type	Size in lbs	Accessory*
0 to 15,000	0 to 46	1	Tractor crawler or rubber-tired	10,000 to 30,000	Dozer blade Landfill blade Front-end loader (1- to 2-yd)
15,000 to 50,000	46 to 155	1	Tractor crawler or rubber-tired	30,000 to 60,000	Dozer blade Landfill blade Front-end loader (2- to 4-yd) Multipurpose bucket
		*	Scraper Dragline Water truck		
50,000 to 100,000	155 to 310	1 to 2	Tractor crawler or rubber-tired	30,000 or more	Dozer blade Landfill blade Front-end loader (2- to 5-yd) Multipurpose bucket
		*	Scraper Dragline Water truck		
100,000 or more	310 or more	2 or more	Tractor crawler or rubber-tired	45,000 or more	Dozer blade Landfill blade Front-end loader Multipurpose bucket
		*	Scraper Dragline Steel-wheel compactor Road grader Water truck		

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* Optional. Dependent on individual need.

the landfill. Other gases typically produced are methane, nitrogen, carbon dioxide, hydrogen, and hydrogen sulfide. At landfills where methane and other gases are generated, the gases should be dissipated into the atmosphere and prevented from concentrating in sewers or other structures located on or near the site.

Leachate Production

The quantities of potential leachate production are significant if good design is not used for the sanitary landfill. The extreme case would be where 100 percent of the precipitation falling on a refuse disposal site percolated through and became leachate. Assuming a precipitation of 36 inches per year after saturation, about 980,000 gallons of contaminated water would result from the water falling on one acre of refuse (9170 cu m/ha). Absorption may approach 100 percent where shredded refuse is allowed to remain without compaction, grading, and cover material.

The leachate produced from a sanitary landfill has been characterized from lysimeter studies and actual operating landfills.[214] The significant pollutants from refuse leachate are reported as BOD, COD, iron, chloride, and nitrate. Other compounds are also found in leachate but in low quantities. Table B-12 contains leachate analyses from various sources.

The leachate produced after refuse has reached saturation or field capacity has a BOD of approximately 2500 mg/l,[216] a COD in the range of 8000 to 10,000 mg/l, an iron concentration of approximately 600 mg/l, and a chloride concentration of approximately 250 mg/l.[214] The initial concentrations were generally higher than the "steady state" conditions indicating a flushing action by water moving through the fill. The concentrations reported tend to be highly variable. This is probably caused in part by lack of standardized refuse compositions, differing amounts of water seeping through the fill, and perhaps sampling and analysis errors resulting from the high concentrations involved and interfering substances. It is evident from the literature that the contaminant concentration decreases with time and amount of water moving through the fill. Studies conducted in California demonstrated that continuous water movement through an acre-foot of refuse would leach out approximately 1.5 tons of sodium plus potassium, 1.0 tons of calcium plus magnesium, 0.91 tons of chloride, 0.23 tons of sulfate, and 3.9 tons of bicarbonate within one year. This would continue in subsequent years but at a reduced rate. It is unlikely that all ions ever would be completely removed.[216]

Leachate may contain biological as well as chemical pollution. The biological pollution is, in nearly every case, filtered out

TABLE B-12

LEACHATE COMPOSITION

Determination (mg/l)	Source[a]					
	1[b]	2[b]	3[b]	4[c]	5[c]	6[c]
pH	5.6	5.9	8.3			
Total hardness ($CaCO_3$)	8,120	3,260	537		8,700	500
Iron total	305	336	219	1,000		
Sodium	1,805	350	600			
Potassium	1,860	655				
Sulfate	630	1,220	99		940	24
Chloride	2,240		300	2,000	1,000	220
Nitrate		5	18			
Alkalinity as $CaCO_3$	8,100	1,710	1,290			
Ammonia nitrogen	845	141				
Organic nitrogen	550	152				
COD		7,130		750,000		
BOD	32,400	7,050		720,000		
Total dissolved solids		9,190	2,000		11,254	2,075

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[a] No age of fill specified for Sources 1-3; Source 4 is initial leachate composition; Source 5 is from 3-year-old, and Source 6 is from 15-year-old fill.

[b] Data from Reference 215.

[c] Data from Reference 214.

of the leachate or adsorbed on soil particles within a few or at the most 100 feet. The travel may be much greater when the leachate becomes part of a surface water system if it enters fissured or channeled rock. If a sanitary landfill site is properly selected and operated, biological pollution beyond the immediate refuse disposal area should not be a problem.

The concentration of chemical pollutants traveling through soil decreases rapidly with distance from the landfill. Studies have shown that 12 feet of soil can reduce BOD by 95 percent.[214] Partial exceptions to this are chlorides, nitrates, and hardness, which are reduced in concentration primarily by dilution rather than other mechanisms such as adsorption. The travel of carbon dioxide through permeable soils may also increase hardness of water in the area. In some soils, ion exchange is a major factor in soil purification of leachate.

Some authorities have recommended that sanitary landfills not be put in soils with rapid percolation. This precaution would prevent rapid transport of possible leachates into the groundwater system. This is a legitimate concern because studies have shown that pollution travels much farther and more rapidly in permeable soils. However, in all cases, leachate production can be minimized or nearly eliminated by preventing water contact with the refuse by the use of surface and subsurface drainage and properly selected cover material that is graded and seeded.

After saturation is reached, the moisture gained and moisture lost must always be in balance. In a well-designed sanitary landfill with surface and groundwater diverted, the water gained is primarily a function of precipitation falling on the site. The precipitation may infiltrate into the soil or be lost through the processes of evaporation, transpiration, and runoff. In a sanitary landfill, the goal is to prevent infiltration beyond that necessary for supporting the plant cover growth because the moisture movement through the cover material into the refuse will be roughly proportional to the leachate production.

General Assumptions

Ultimate disposal by sanitary landfill was incorporated for disposing of incinerator ash and dewatered sludges. The governing assumptions involved were:[65]

- Operational method utilized appears in Figure B-28.
- Land costs were assumed to be $1,000/acre.

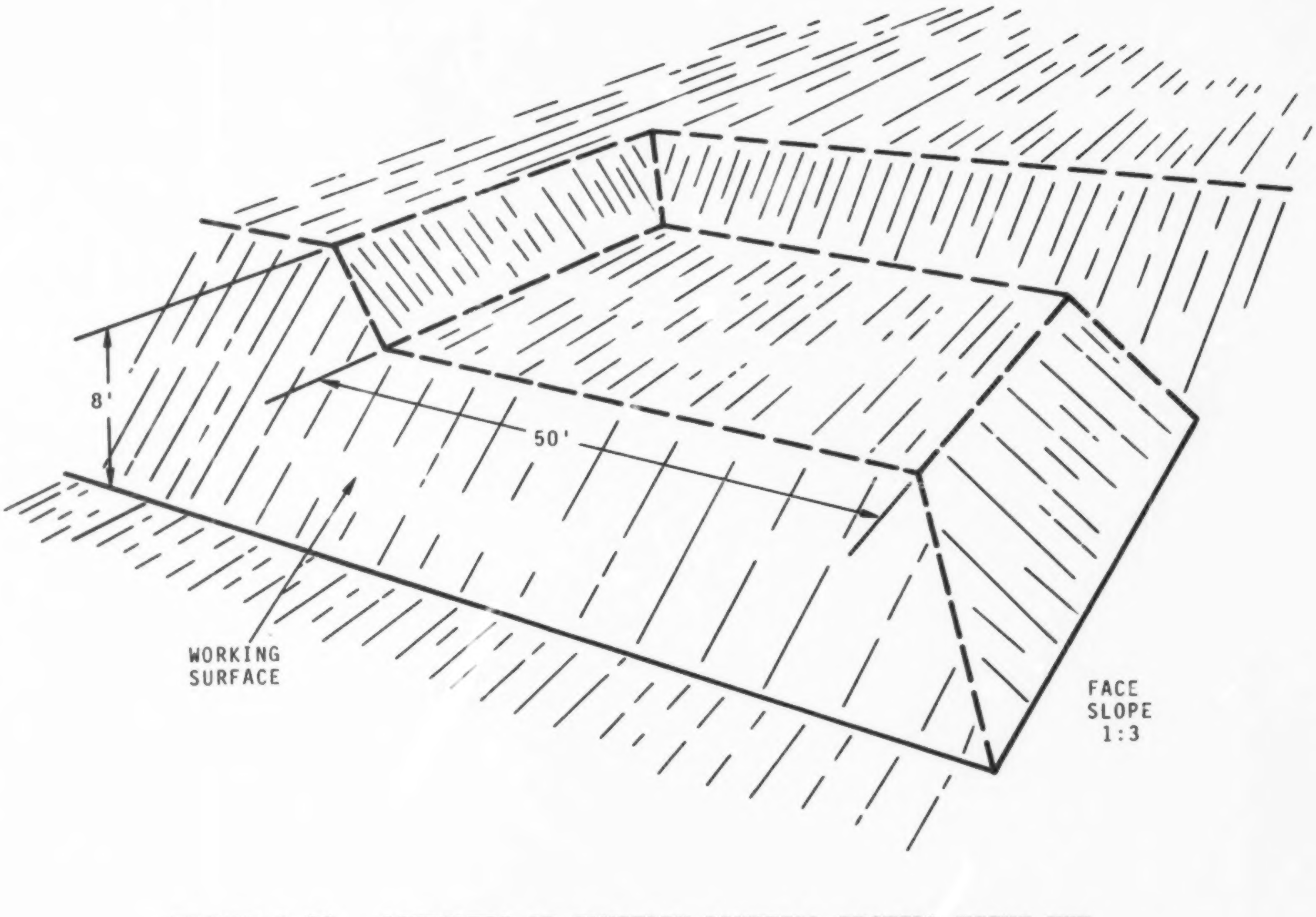
8'
50'
WORKING SURFACE
FACE SLOPE 1:3

FIGURE B-28. SCHEMATIC OF SANITARY LANDFILL PROFILE USING THE RAMP METHOD OF WASTE COVERAGE[65]

- Site preparation costs $1/yard of cover soil.
- Expected site life of 20 years.
- Final use of the site will be for recreational purposes. No resale value was assumed.
- Cell depth was eight feet.

The round trip distances for trucking the sludge as ash were assigned as follows:

Plant Size	Hauling Distance (Miles)
0.1-1.0 MGD	20
10 MGD	50
100 MGD	100
1000 MGD	100

The transportation cost of hauling the sludge was based upon a 20 ton load at a charge-out rate of $0.32/ton of dry solids for the first three miles and $0.10/ton/mile of dry solids for each additional mile.

The capital cost, manpower requirements, and operating costs (other than transportation) were developed from Figures B-29, B-30, and B-31, respectively.[65] Area requirements were based on 3.75 x 10^{-3} acre/ton of dry solids/year.[65]

DESIGN PARAMETERS FOR INDIVIDUAL SLUDGE OPTIONS

The various design parameters utilized for the development of the numerical figures on the profile sheets are presented in the following tables. In most cases, the figures presented on these tables represent the average of the reported design parameters or performance factors.

It should be remembered that the overall performance of a particular sludge option is dependent upon the operational efficiency of each individual unit operation comprising the sludge handling scheme. Should the efficiency of any one unit drop, the characteristics of the sludge leaving that unit will change with consequent disruption of the performance of succeeding units. For instance, failure of the gravity or flotation thickener to produce a thickened sludge will result in the necessity of adding an ever increased amount of polymers during the conditioning phase in order to realize the same cake moisture content and solids recovery. On the other hand, if

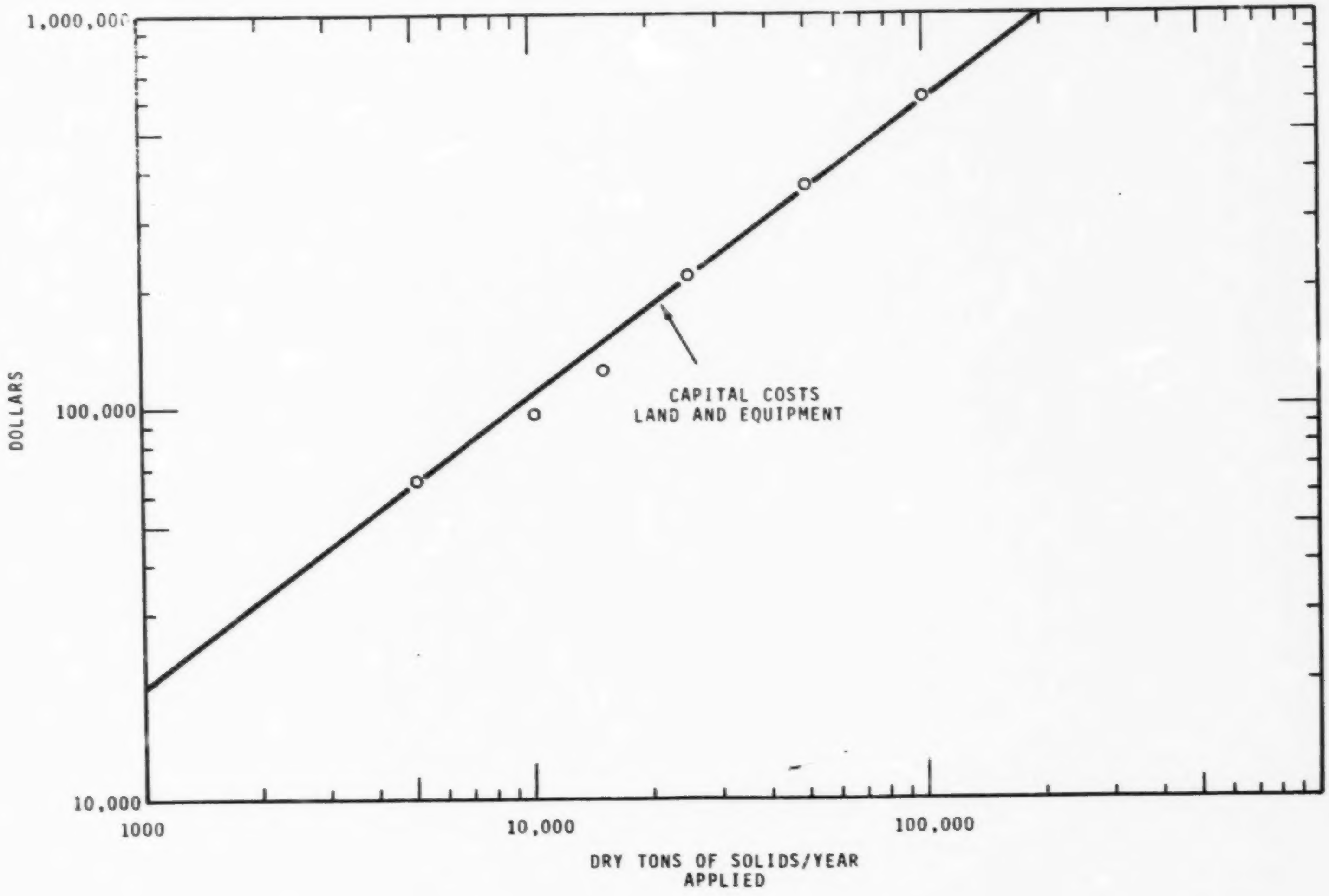

FIGURE B-29. SANITARY LANDFILL CAPITAL COSTS[65]

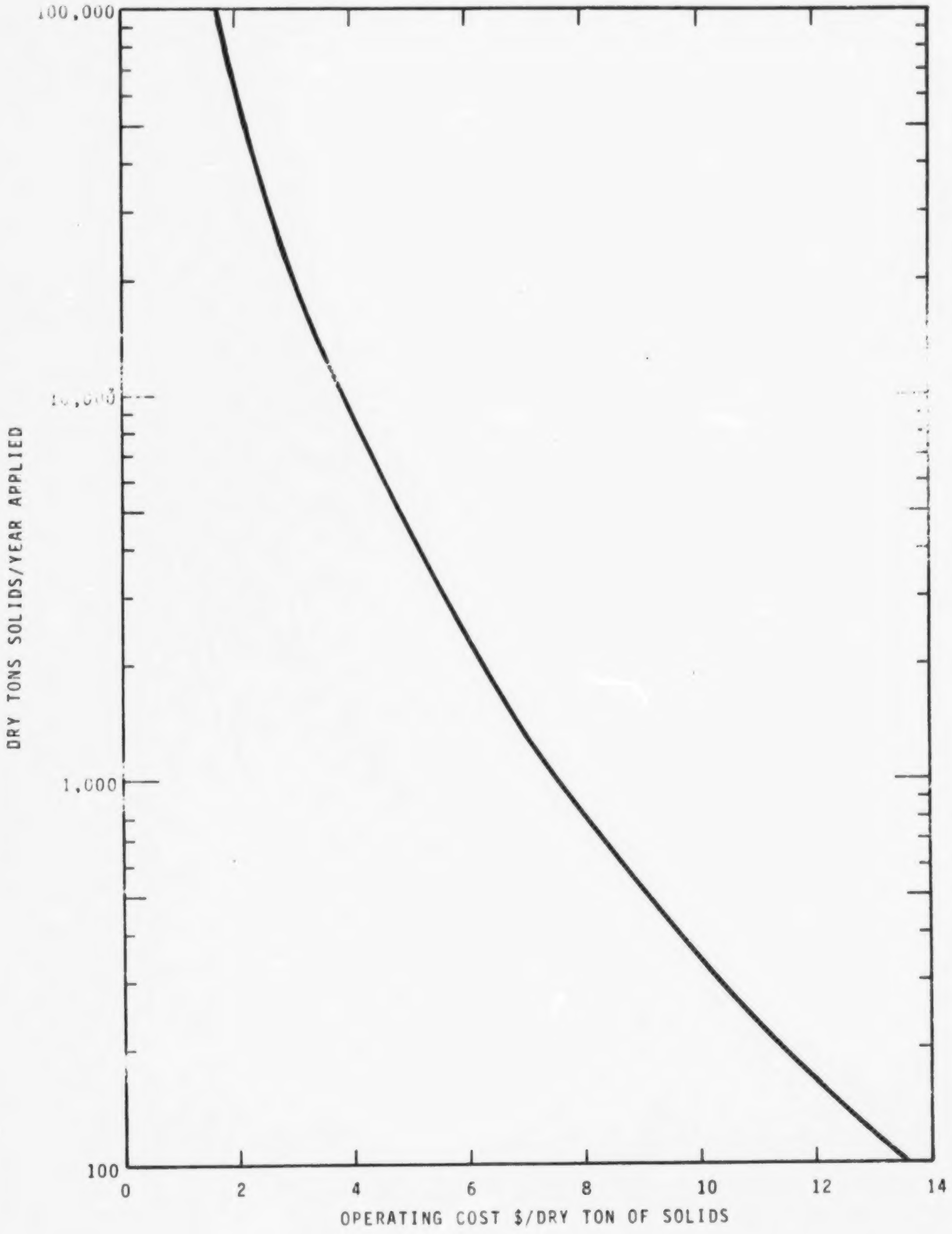

FIGURE B-30. SANITARY LANDFILL OPERATING COSTS[65]

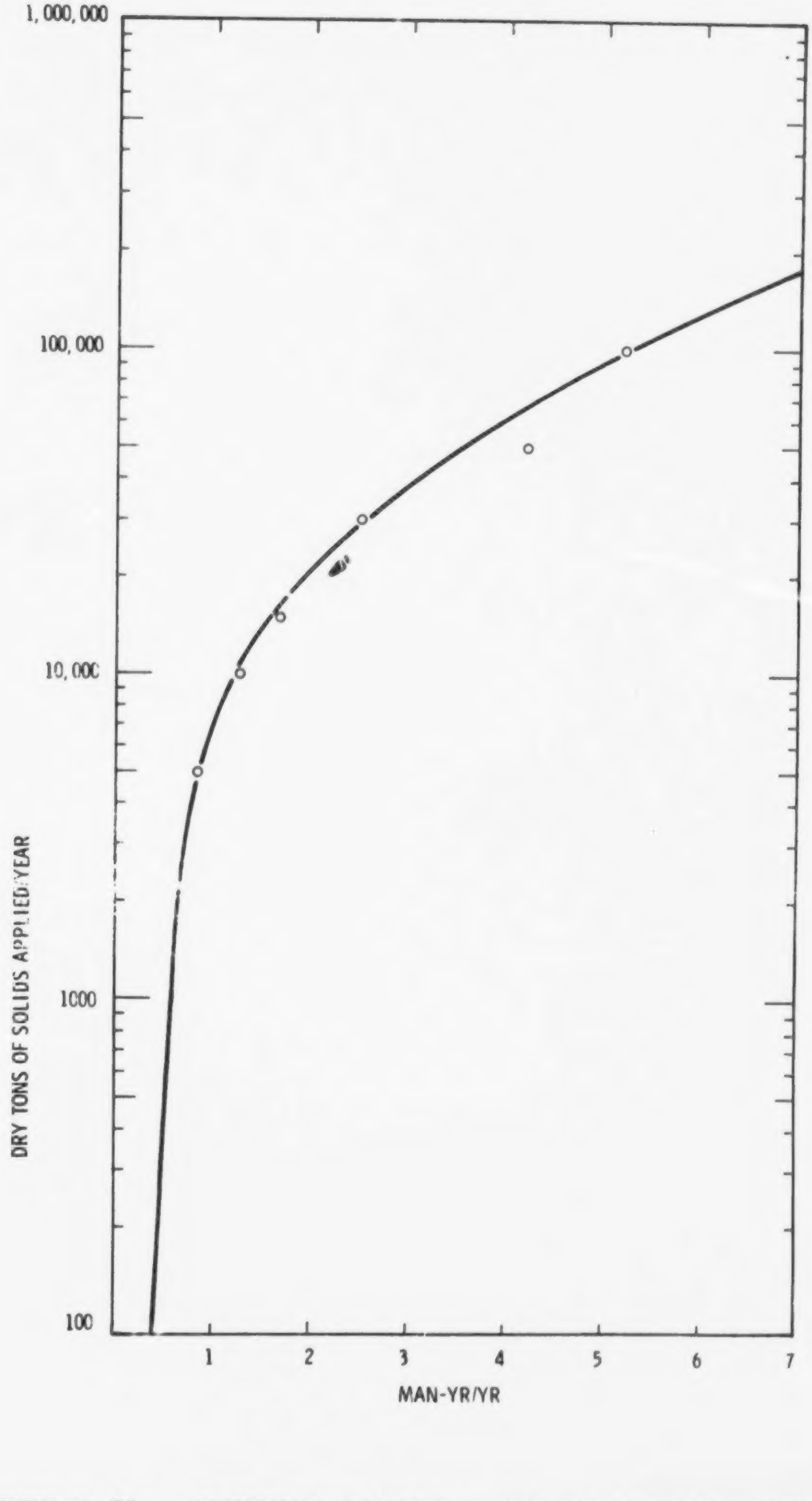

FIGURE B-31. SANITARY LANDFILL MAN-HOUR REQUIREMENTS[65] the vacuum filter fails to perform adequately, the higher moisture content of the sludge cake will require the incinerator's auxiliary fuel consumption to increase in order to maintain a minimum combustion temperature of 1400°F. A further increase in moisture content will lower the combustion temperature below the minimum, increasing the opportunity for incomplete combustion and the subsequent release of odors and violation of air pollution standards.

Sanitary landfill of the residual ash from the incinerator should be unaffected by the performance of the preceding unit operations.

Sludge Option 1

In Sludge Option 1, sludge is removed from the clarifiers, thickened by gravity or air flotation (depending upon sludge type) with the thickener overflow being recycled to the head end of the plant, conditioned by the utilization of polymers (if such treatment is appropriate), dewatered by vacuum filtration including filtrate recycle to the plant influent, incinerated in a multiple hearth unit, and disposed of in a sanitary landfill. System design parameters are given in Table B-13.

Sludge Option 2

For the second sludge option, incoming sludge from the clarifiers and treatment systems is conditioned by a polymer, dewatered by centrifuge with the centrate being recycled to the plant's head end, incinerated in a multiple hearth incinerator, and disposed of at a sanitary landfill. The process can be operated continuously or intermittently. System design parameters are given in Table B-14.

Sludge Option 3

For Sludge Option 3, the sludge is thickened and the overflow is returned to the plant. Then the sludge is heat treated in the porteous unit with the portrate being recycled to the plant influent. The sludge, with improved dewatering characteristics, is then passed to a vacuum filter where the filtrate is also returned to the plant influent and the cake is transported to the incinerator where the final product is an inert ash which is disposed of in a sanitary landfill. Table B-15 contains the system design parameters used in this work.

Sludge Option 4

For Sludge Option 4, sludge from the treatment system is initially thickened with the thickener overflow being returned

TABLE B-13

SLUDGE OPTION 1 DESIGN PARAMETERS

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETERS	PLANT SIZE (MGD)			
			1.0	10	100	1000
PRIMARY	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	20	20		
		Influent (% solids)	2.5-5	2.5-5		
		Effluent (% solids)	5-8	5-8		
	II) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4		
		Operating shift (hrs)	6	6		
		Cake (% solids)	20-30	20-30		
	III) Incineration	Pounds per hour	45	450		
		Weight reduction (%)	70	70		
	IV) Sanitary Landfill	Tons per day	0.16	1.6		
TRICKLING FILTER HUMUS + PRIMARY	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	10	10	10	10
		Influent (% solids)	3-6	3-6	3-6	3-6
		Effluent (% solids)	7-9	7-9	7-9	7-9
	II) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4	4	4
		Operating shift (hrs)	6	6	12	12
		Cake (% solids)	20-30	20-30	20-30	20-30
	III) Incineration	Pounds per hour	58	580	5800	58,000
		Weight reduction (%)	68	68	68	68
	IV) Sanitary Landfill	Tons per day	0.23	2.25	22.5	225
ACTIVATED + PRIMARY	I) Flotation Thickening	Loading factor (lbs/hr/ft^2)	2	2	2	2
		Influent (% solids)	1-2	1-2	1-2	1-2
		Effluent (% solids)	4-6	4-6	4-6	4-6
	II) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4	4	4
		Operating shift (hrs)	6	6	12	12
		Cake (% solids)	20-30	20-30	20-30	20-30
	III) Incineration	Pounds per hour	97	970	9700	97,000
		Weight reduction (%)	70	70	70	70
	IV) Sanitary Landfill	Tons per day	0.35	3.5	35	350

TABLE B-13 (Cont'd.)

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETERS	PLANT SIZE (MGD) 1.0	10	100	1000
ACTIVATED + PRIMARY + ALUM PRECIPITATE	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)		8	6	8
		Influent (% solids)		0.5-1	0.5-1	0.5-1
		Effluent (% solids)		2-5	2-5	2-5
	II) Vacuum Filtration	Filter yield (lbs/sq ft/hr)		2	2	2
		Operating shift (hrs)		12	18	18
		Cake (% solids)		15-30	15-30	15-30
	III) Incineration	Pounds per hour		1567	15,670	156,700
		Weight reduction (%)		62	62	62
	IV) Sanitary Landfill	Tons per day		7	70	705

TABLE B-14

SLUDGE OPTION 2 DESIGN PARAMETERS

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETERS	PLANT SIZE (MGD)			
			1.0	10	100	1000
PRIMARY	I) Centrifuge	Inflow rate (gpm)	1.8	18		
		Influent (% solids)	2.5-5	2.5-5		
		Effluent (% solids)	25-35	25-35		
	II) Incineration	Pounds per hour	45	450		
		Weight reduction (%)	70	70		
	III) Sanitary Landfill	Tons per day	0.16	1.6		
TRICKLING FILTER HUMUS + PRIMARY	I) Centrifuge	Inflow rate (gpm)	2.3	23	230	2300
		Influent (% solids)	3-6	3-6	3-6	3-6
		Effluent (% solids)	20-26	20-26	20-26	20-26
	II) Incineration	Pounds per hour	58	580	5800	58,000
		Weight reduction (%)	68	68	68	68
	III) Sanitary Landfill	Tons per day	0.23	2.3	23	230
ACTIVATED + PRIMARY	I) Centrifuge	Inflow rate (gpm)	18	180	1800	18,000
		Influent (% solids)	1-2	1-2	1-2	1-2
		Effluent (% solids)	15-30	15-30	15-30	15-30
	II) Incineration	Pounds per hour	97	970	9700	97,000
		Weight reduction (%)	70	70	70	70
	III) Sanitary Landfill	Tons per day	0.35	3.5	35	350
ACTIVATED + PRIMARY + ALUM PRECIPITATE	I) Centrifuge	Inflow rate (gpm)		314	3140	31,400
		Influent (% solids)		0.5-1	0.5-1	0.5-1
		Effluent (% solids)		16-20	16-20	16-20
	II) Incineration	Pounds per hour		1567	15,670	156,700
		Weight reduction (%)		62	62	62
	III) Sanitary Landfill	Tons per day		7	70	705

TABLE B-15

SLUDGE OPTION 3 DESIGN PARAMETERS

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETERS	PLANT SIZE (MGD)			
			1.0	10	100	1000
PRIMARY	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	20	20		
		Influent (% solids)	2.5-5	2.5-5		
		Effluent (% solids)	5-8	5-8		
	II) Porteous	Inflow rate (gpm)	1.8	18		
		Effluent (% solids)	8-12	8-12		
		Weight reduction (%)	25	25		
	III) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	8	8		
		Operating shift (hrs)	6	6		
		Cake (% solids)	30-50	30-50		
	IV) Incineration	Pounds per hour	34	340		
		Weight reduction (%)	70	70		
	V) Sanitary Landfill	Tons per day	0.12	1.2		
TRICKLING FILTER + PRIMARY	I) Gravity Thickening	Mass loading (lbs/day/ft^2)	10	10	10	10
		Influent (% solids)	3-6	3-6	3-6	3-6
		Effluent (% solids)	7-9	7-9	7-9	7-9
	II) Porteous	Inflow rate (gpm)	1.6	16	160	1600
		Effluent (% solids)	8-12	8-12	8-12	8-1
		Weight reduction (%)	25	25	25	25
	III) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	8	8	8	8
		Operating shift (hrs)	6	6	12	12
		Cake (% solids)	30-50	30-50	30-50	30-50
	IV) Incineration	Pounds per hour	44	440	4400	44,000
		Weight reduction (%)	70	70	70	70
	V) Sanitary Landfill	Tons per day	0.16	1.6	16	160
ACTIVATED + PRIMARY	I) Flotation Thickening	Loading factor (lbs/hr/ft^2)	2	2	2	2
		Influent (% solids)	1-2	1-2	1-2	1-2
		Effluent (% solids)	4-6	4-6	4-6	4-6
	II) Porteous	Inflow rate (gpm)	3.8	38	388	3880
		Effluent (% solids)	8-12	8-12	8-12	8-12
		Weight reduction (%)	25	25	25	25
	III) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	8	8	8	8
		Operating shift (hrs)	6	6	12	12
		Cake (% solids)	30-50	30-50	30-50	30-50
	IV) Incineration	Pounds per hour	73	730	7300	73,000
		Weight reduction (%)	70	70	70	70
	V) Sanitary Landfill	Tons per day	0.26	2.6	26	260

TABLE B-15 (Cont'd.)

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETERS	PLANT SIZE (MGD) 1.0	10	100	1000
ACTIVATED + PRIMARY + ALUM PRECIPITATE	I) Gravity Thickening	Mass loading (lbs/day/ft^2)		8	8	8
		Influent (% solids)		0.5-1	0.5-1	0.5-1
		Effluent (% solids)		2-5	2-5	2-5
	II) Porteous	Inflow rate (gpm)		62	626	6260
		Effluent (% solids)		8-12	8-12	8-12
		Weight reduction (%)		25	25	25
	III) Vacuum Filtration	Filter yield (lbs/sq ft/hr)		8	8	8
		Operating shift		6	12	12
		Cake (% solids)		30-50	30-50	30-50
	IV) Incineration	Pounds per hour		1175	11,750	117,500
		Weight reduction (%)		70	70	70
	V) Sanitary Landfill	Tons per day		4.2	42	423

to the plant. The thickened sludge is anaerobically digested and applied to a sand drying bed. After completion of the drying process, the sludge is removed and hauled to a sanitary landfill site. System design parameters are given in Table B-16.

Sludge Option 5

For the fifth sludge option, sludge is collected from the wastewater treatment system, thickened with the overflow being recycled to the plant influent, digested anaerobically, and transported to a designated region for land spreading. Hauling the slurry by truck transportation was utilized for plants of 10 MGD or less and pipeline transportation was provided for plants larger than 10 MGD. System design parameters are given in Table B-17.

Sludge Option 6

For Sludge Option 6, sludge is collected from the various wastewater treatment systems, thickened by gravity or air flotation methods (depending upon the sludge characteristics), anaerobically digested for pathogen and odor control, and transported to the ocean by pipeline. System design parameters are given in Table B-18.

Due to the capital intensiveness of ocean pipelines, this option was considered only for plants larger than 10 MGD.

Sludge Option 7

For the seventh option, sludge is collected and thickened by an appropriate method, anaerobically digested, and dewatered with a vacuum filter. Thickener overflow and filtrate are recycled to the plant influent. The filter cake is disposed of in a sanitary landfill after hauling by truck. System design parameters are given in Table B-19.

Sludge Option 8

For Sludge Option 8, sludges collected from the various treatment schemes considered are combined and, depending on the type of sludge, are gravity or air flotation thickened. Thickened sludge is then passed through an anaerobic digester for pathogen and odor control. Sludge exiting from the preceding process is vacuum filtered with the filtrate being returned to the plant's head end. The filter cake is transported by barge to the ocean for disposal. Design parameters for this sludge option are given in Table B-20.

TABLE B-16

SLUDGE OPTION 4 DESIGN PARAMETERS

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETER	PLANT SIZE (MGD)			
			1.0	10	100	1000
PRIMARY	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2	20	20		
		Influent (% solids)	2.5-5	2.5-5		
		Effluent (% solids)	5-8	5-8		
	II) Anaerobic Digestion	Influent solids (lbs/day)	1080	10,800		
		Weight reduction (%)	30	30		
	III) Sand Drying	Cake (% solids)	25-50	25-50		
	IV) Sanitary Landfill	Tons per day	0.37	3.7		
TRICKLING FILTER + PRIMARY	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	10	10	10	10
		Influent (% solids)	3-6	3-6	3-6	3-6
		Effluent (% solids)	7-9	7-9	7-9	7-9
	II) Anaerobic Digestion	Influent solids (lbs/day)	1400	14,000	140,000	1,400,000
		Weight reduction (%)	34	34	34	34
	III) Sand Drying	Cake (% solids)	25-50	25-50	25-50	25-50
	IV) Sanitary Landfill	Tons per day	0.46	4.6	46	460
ACTIVATED SLUDGE + PRIMARY	I) Flotation Thickening	Loading factor (lbs/hr/ft^2)	2	2	2	2
		Influent (% solids)	1-2	1-2	1-2	1-2
		Effluent (% solids)	4-6	4-6	4-6	4-6
	II) Anaerobic Digestion	Influent solids (lbs/day)	2330	23,300	233,000	2,330,000
		Weight reduction (%)	39	39	39	39
	III) Sand Drying	Cake (% solids)	25-50	25-50	25-50	25-50
	IV) Sanitary Landfill	Tons per day	0.7	7	70	700
ACTIVATED + PRIMARY + ALUM PRECIPITATE	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)		8	8	8
		Influent (% solids)		0.5-1	0.5-1	0.5-1
		Effluent (% solids)		2-5	2-5	2-5
	II) Anaerobic Digestion	Influent solids (lbs/day)		37,600	376,000	3,760,000
		Weight reduction (%)		50	50	50
	III) Sand Drying	Cake (% solids)		25-50	25-50	25-50
	IV) Sanitary Landfill	Tons per day		9.4	94	940

TABLE B-17

SLUDGE OPTION 5 DESIGN PARAMETERS

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETERS	PLANT SIZE (MGD)			
			1.0	10	100	1000
PRIMARY	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	20	20		
		Influent (% solids)	2.5-5	2.5-5		
		Effluent (% solids)	5-8	5-8		
	II) Anaerobic Digestion	Influent solids (lbs/day)	1080	10,800		
		Weight reduction (%)	30	30		
	III) Land Spreading	Percent solids	6-8	6-8		
		Tons per day	0.37	3.7		
TRICKLING FILTER + PRIMARY	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	10	10	10	10
		Influent (% solids)	3-6	3-6	3-6	3-6
		Effluent (% solids)	7-9	7-9	7-9	7-9
	II) Anaerobic Digestion	Influent solids (lbs/day)	1400	14,000	140,000	1,400,000
		Weight reduction (%)	34	34	34	34
	III) Land Spreading	Percent solids	7-8	7-8	7-8	7-8
		Tons per day		4.6	46	460
ACTIVATED + PRIMARY	I) Flotation Thickening	Loading factor (lbs/hr/ft^2)	[illegible]	2	2	2
		Influent (% solids)	1-2	1-2	1-2	1-2
		Effluent (% solids)	4-6	4-6	4-6	4-6
	II) Anaerobic Digestion	Influent solids (lbs/day)	2330	23,300	233,000	2,330,000
		Weight reduction (%)	39	39	39	39
	III) Land Spreading	Percent solids	6-8	6-8	6-8	6-8
		Tons per day	0.7	7	70	700
ACTIVATED + PRIMARY + ALUM PRECIPITATE	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)		8	8	8
		Influent (% solids)		0.5-1	0.5-1	0.5-1
		Effluent (% solids)		2-5	2-5	2-5
	II) Anaerobic Digestion	Influent solids (lbs/day)		37,600	376,000	3,760,000
		Weight reduction (%)		50	50	50
	III) Land Spreading	Percent solids		5-7	5-7	5-7
		Tons per day		9.4	94	940

TABLE B-18

SLUDGE OPTION 6 DESIGN PARAMETERS

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETERS	PLANT SIZE (MGD) 1.0	10	100	100
TRICKLING FILTER + PRIMARY	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)			10	10
		Influent (% solids)			3-6	3-6
		Effluent (% solids)			7-9	7-9
	II) Anaerobic Digestion	Influent solids (lbs/day)			140,000	1,400,000
		Weight reduction (%)			34	34
	III) Ocean Dumping	Tons per day			46	460
ACTIVATED + PRIMARY	I) Flotation Thickening	Loading factor (lbs/hr/ft^2)			2	2
		Influent (% solids)			1-2	1-2
		Effluent (% solids)			4-6	4-6
	II) Anaerobic Digestion	Influent solids (lbs/day)			233,000	2,330,000
		Weight reduction (%)			39	39
	III) Ocean Dumping	Tons per day			70	700
ACTIVATED + PRIMARY + ALUM PRECIPITATE	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)			8	8
		Influent (% solids)			0.5-1	0.5-1
		Effluent (% solids)			2-5	2-5
	II) Anaerobic Digestion	Influent solids (lbs/day)			376,000	3,760,000
		Weight reduction (%)			50	50
	III) Ocean Dumping	Tons per day			94	940

TABLE B-19

SLUDGE OPTION 7 DESIGN PARAMETERS

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETERS	PLANT SIZE (MGD) 1.0	10	100	1000
PRIMARY	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	20	20		
		Influent (% solids)	2.5-5	2.5-5		
		Effluent (% solids)	5-8	5-8		
	II) Anaerobic Digestion	Influent solids (lbs/day)	1080	10,800		
		Weight reduction (%)	30	30		
	III) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4		
		Operating shifts (hrs)	6	6		
		Cake (% solids)	20-30	20-30		
	IV) Sanitary Landfill	Tons per day	0.37	3.7		
TRICKLING FILTER HUMUS + PRIMARY	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	10	10	10	10
		Influent (% solids)	3-6	3-6	3-6	3-6
		Effluent (% solids)	7-9	7-9	7-9	7-9
	II) Anaerobic Digestion	Influent solids (lbs/day)	1400	14,000	140,000	1,400,000
		Weight reduction (%)	34	34	34	34
	III) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4	4	4
		Operating shifts (hrs)	6	6	6	12
		Cake (% solids)	20-30	20-30	20-30	20-30
	IV) Sanitary Landfill	Tons per day	0.46	4.6	46	460
ACTIVATED + PRIMARY	I) Flotation Thickening	Loading factor (lbs/ [illegible] ^{2})	2	2	2	2
		Influent (% solids)	1-2	1-2	1-2	1-2
		Effluent (% solids)	4-6	4-6	4-6	4-6
	II) Anaerobic Digestion	Influent solids (lbs/day)	2330	23,300	233,000	2,330,000
		Weight reduction (%)	39	39	39	39
	III) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4	4	4
		Operating shifts (hrs)	6	6	12	12
		Cake (% solids)	20-30	20-30	20-30	20-30
	IV) Sanitary Landfill	Tons per day	0.7	7	70	700
ACTIVATED + PRIMARY + ALUM PRE-CIPITATE	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)		8	8	8
		Influent (% solids)		0.5-1	0.5-1	0.5-1
		Effluent (% solids)		2-5	2-5	2-5
	II) Anaerobic Digestion	Influent solids (lbs/day)		37,600	376,000	3,760,000
		Weight reduction (%)		50	50	50
	III) Vacuum Filtration	Filter yield (lbs/sq ft/hr)		2	2	2
		Operating shifts (hrs)		6	12	12
		Cake (% solids)		15-30	15-30	15-30
	IV) Sanitary Landfill	Tons per day		9.4	94	940

TABLE B-20

SLUDGE OPTION 8 DESIGN PARAMETERS

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETERS	PLANT SIZE (MGD) 1.0	10	100	1000
PRIMARY	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	20	20		
		Influent (% solids)	2.5-5	2.5-5		
		Effluent (% solids)	5-8	5-8		
	II) Anaerobic Digestion	Influent solids (lbs/day)	1080	10,800		
		Weight reduction (%)	30	30		
	III) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4		
		Operating shifts (hrs)	6	6		
		Cake (% solids)	20-30	20-30		
	IV) Ocean Dumping	Tons per day	0.37	3.7		
TRICKLING FILTER HUMUS + PRIMARY	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	10	10	10	10
		Influent (% solids)	3-6	3-6	3-6	3-6
		Effluent (% solids)	7-9	7-9	7-9	7-9
	II) Anaerobic Digestion	Influent solids (lbs/day)	1400	14,000	140,000	1,400,000
		Weight reduction (%)	34	34	34	34
	III) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4	4	4
		Operating shifts (hrs)	6	6	12	12
		Cake (% solids)	20-30	20-30	20-30	20-30
	IV) Ocean Dumping	Tons per day	0.46	4.6	46	460
ACTIVATED + PRIMARY	I) Flotation Thickening	Loading factor (lbs/hr/ft^2)	2	2	2	2
		Influent (% solids)	1-2	1-2	1-2	1-2
		Effluent (% solids)	4-6	4-6	4-6	4-6
	II) Anaerobic Digestion	Influent solids (lbs/day)	2330	23,300	230,000	2,300,000
		Weight reduction (%)	39	39	39	39
	III) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4	4	4
		Operating shifts (hrs)	6	6	12	12
		Cake (% solids)	20-30	20-30	20-30	20-30
	IV) Ocean Dumping	Tons per day	0.7	7	70	700

TABLE B-20 (Cont'd.)

			PLANT SIZE (MGD)			
SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETERS	1.0	10	100	1000
ACTIVATED + PRIMARY + ALUM PRE-CIPITATE	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)		8	8	8
		Influent (% solids)		0.5-1	0.5-1	0.5-1
		Effluent (% solids)		2-5	2-5	2-5
	II) Anaerobic Digestion	Influent solids (lbs/day)		37,600	376,000	3,760,000
		Weight reduction (%)		50	50	50
	III) Vacuum Filtration	Filter yield (lbs/sq ft/hr)		2	2	2
		Operating shifts (hrs)		6	12	12
		Cake (% solids)		15-30	15-30	15-30
	IV) Ocean Dumping	Tons per day		9.4	94	940

Sludge Option 9

This chemical sludge option calls for gravity thickening, vacuum filtration, incineration, and sanitary landfill. The lime sludge is gravity thickened with the overflow being recycled to the plant influent. The thickened sludge is vacuum filtered with the filtrate also recycled to the plant influent. The cake is then incinerated and the lime and ash are disposed of in a sanitary landfill. Table B-21 contains the design parameters utilized in this analysis.

Sludge Option 10

Sludge Option 10 consists of gravity thickening, vacuum filtration, recalcination, lime reuse, and landfill of recalciner blowdown. The chemical sludge is gravity thickened (recycling the overflow to the influent), vacuum filtered (with the filtrate being recycled), and recalcinated in a multiple hearth incinerator. The lime is recycled for its value as a chemical coagulant. Approximately 25 percent (by weight) is wasted and disposed of in a sanitary landfill. Table B-22 contains design data used in this analysis.

Sludge Option 11

The eleventh sludge option consists of gravity thickening, centrifugation, incineration, and sanitary landfill. Lime sludges are collected from the wastewater treatment systems, thickened by gravitation (recycling the overflow), dewatered by centrifugation (recycling the centrate), incinerated in a multiple hearth unit, and disposed of at a sanitary landfill site. Design parameters for this system are given in Table B-23.

Sludge Option 12

In the final sludge option, the chemical sludges are gravity thickened and the overflow is recycled to the plant influent. The thickened sludge is dewatered by centrifuge with the centrate recycled to the plant. The dewatered cake is recalcinated in a multiple hearth unit to recover the lime for reuse. Twenty-five percent of the recalcined lime is wasted to a sanitary landfill. Design parameters are given in Table B-24.

TABLE B-21

SLUDGE OPTION 9 DESIGN PARAMETERS

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETER	PLANT SIZE (MGD)		
			10	100	1000
LIME SLUDGE FROM TREATMENT STRATEGY 8	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	50	50	50
		Influent (% solids)	0.5-1	0.5-1	0.5-1
		Effluent (% solids)	8-20	8-20	8-20
	II) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4	4
		Operating shifts (hrs)	6	18	18
		Cake (% solids)	35-45	35-45	35-45
	III) Incineration	Pounds per hour	1837	18,370	183,700
		Weight reduction (%)	20	20	20
	IV) Sanitary Landfill	Tons per day	17.6	176	1760
LIME SLUDGE FROM TREATMENT STRATEGY 9	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	50	50	50
		Influent (% solids)	0.5-1	0.5-1	0.5-1
		Effluent (% solids)	8-20	8-20	8-20
	II) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4	4
		Operating shifts (hrs)	6	18	18
		Cake (% solids)	35-45	35-45	35-45
	III) Incineration	Pounds per hour	1891	18,910	189,100
		Weight reduction (%)	20	20	20
	IV) Sanitary Landfill	Tons per day	18.1	181	1815
LIME SLUDGE FROM TREATMENT STRATEGY 10	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	50	50	50
		Influent (% solids)	0.5-1	0.5-1	0.5-1
		Effluent (% solids)	8-20	8-20	8-20
	II) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4	4
		Operating shifts (hrs)	6	18	18
		Cake (% solids)	35-45	35-45	35-45
	III) Incineration	Pounds per hour	2862	28,625	286,250
		Weight reduction (%)	20	20	20
	IV) Sanitary Landfill	Tons per day	27	275	2750

TABLE B-22

SLUDGE OPTION 10 DESIGN PARAMETERS

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETER	PLANT SIZE (MGD) 10	100	1000
LIME SLUDGE FROM TREATMENT STRATEGY 8	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	50	50	50
		Influent (% solids)	0.5-1	0.5-1	0.5-1
		Effluent (% solids)	8-20	8-20	8-20
	II) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4	4
		Operating shifts (hrs)	18	18	18
		Cake (% solids)	35-45	35-45	35-45
	III) Recalcination	Pounds per hour	3225	32,250	322,500
		Weight reduction (%)	20	20	20
	IV) Sanitary Landfill	Tons per day	10.3	103	1030
LIME SLUDGE FROM TREATMENT STRATEGY 9	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	50	50	50
		Influent (% solids)	0.5-1	0.5-1	0.5-1
		Effluent (% solids)	8-20	8-20	8-20
	II) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4	4
		Operating shifts (hrs)	18	18	18
		Cake (% solids)	35-45	35-45	35-45
	III) Recalcination	Pounds per hour	3379	33,790	337.900
		Weight reduction (%)	20	20	20
	IV) Sanitary Landfill	Tons per day	10.8	108	1080
LIME SLUDGE FROM TREATMENT STRATEGY 10	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	50	50	50
		Influent (% solids)	0.5-1	0.5-1	0.5-1
		Effluent (% solids)	8-20	8-20	8-20
	II) Vacuum Filtration	Filter yield (lbs/sq ft/hr)	4	4	4
		Operating shifts (hrs)	18	18	18
		Cake (% solids)	35-45	35-45	35-45
	III) Recalcination	Pounds per hour	6166	61,660	616,600
		Weight reduction (%)	20	20	20
	IV) Sanitary Landfill	Tons per day	20.1	201	2015

TABLE B-23

SLUDGE OPTION 11 DESIGN PARAMETERS

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETER	PLANT SIZE (MGD) 10	PLANT SIZE (MGD) 100	PLANT SIZE (MGD) 1000
LIME SLUDGE FROM TREATMENT STRATEGY 8	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	50	50	50
		Influent (% solids)	0.5-1	0.5-1	0.5-1
		Effluent (% solids)	8-20	8-20	8-20
	II) Centrifugation	Inflow rate (gpm)	46	460	4600
		Effluent (% solids)	35-40	35-40	35-40
	III) Incineration	Pounds per hour	1837	18,370	183,700
		Weight reduction (%)	20	20	20
	IV) Sanitary Landfill	Tons per day	17.6	176	1760
LIME SLUDGE FROM TREATMENT STRATEGY 9	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	50	50	50
		Influent (% solids)	0.5-1	0.5-1	0.5-1
		Effluent (% solids)	8-20	8-20	8-20
	II) Centrifugation	Inflow rate (gpm)	47	470	4700
		Effluent (% solids)	35-40	35-40	35-40
	III) Incineration	Pounds per hour	1891	18,910	189,100
		Weight reduction (%)	20	20	20
	IV) Sanitary Landfill	Tons per day	18.1	181	1815
LIME SLUDGE FROM TREATMENT STRATEGY 10	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	50	50	50
		Influent (% solids)	0.5-1	0.5-1	0.5-1
		Effluent (% solids)	8-20	8-20	8-20
	II) Centrifugation	Inflow rate (gpm)	71.5	715	7150
		Effluent (% solids)	35-40	35-40	35-40
	III) Incineration	Pounds per hour	2862	28,625	286,250
		Weight reduction (%)	20	20	20
	IV) Sanitary Landfill	Tons per day	27	275	2750

TABLE B-24

SLUDGE OPTION 12 DESIGN PARAMETERS

SLUDGE TYPE	UNIT OPERATION	DESIGN PARAMETER	PLANT SIZE (MGD)		
			10	100	1000
LIME SLUDGE FROM TREATMENT STRATEGY 8	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	50	50	50
		Influent (% solids)	0.5-1	0.5-1	0.5-1
		Effluent (% solids)	8-20	8-20	8-20
	II) Centrifugation	Inflow rate (gpm)	80	805	8058
		Effluent (% solids)	35-40	35-40	35-40
	III) Recalcination	Pounds per hour	3225	32,250	322,500
		Weight reduction (%)	20	20	20
	IV) Sanitary Landfill	Tons per day	10.3	103	1030
LIME SLUDGE FROM TREATMENT STRATEGY 9	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	50	50	50
		Influent (% solids)	0.5-1	0.5-1	0.5-1
		Effluent (% solids)	8-20	8-20	8-20
	II) Centrifugation	Inflow rate (gpm)	84	844	8448
		Effluent (% solids)	35-40	35-40	35-40
	III) Recalcination	Pounds per hour	3379	33,790	337,900
		Weight reduction (%)	20	20	20
	IV) Sanitary Landfill	Tons per day	10.8	108	1080
LIME SLUDGE FROM TREATMENT STRATEGY 10	I) Gravity Thickening	Mass loading rate (lbs/day/ft^2)	50	50	50
		Influent (% solids)	0.5-1	0.5-1	0.5-1
		Effluent (% solids)	8-20	8-20	8-20
	II) Centrifugation	Inflow rate (gpm)	154	1540	15,408
		Effluent (% solids)	35-40	35-40	35-40
	III) Recalcination	Pounds per hour	6166	61,660	616,600
		Weight reduction (%)	20	20	20
	IV) Sanitary Landfill	Tons per day	20.1	201	2015

MAJOR DESIGN ASSUMPTIONS

All operations are assumed to be accomplished within the existing regulatory requirements. Consequently, effluent standards for air and water, pretreatment requirements for toxic substances, and specific operating guidelines for such practices as ocean dumping and incineration are anticipated in the data. The effect of such assukptions is largely seen in the capital and operating costs where additional equipment and higher input requirements are necessitated.

The operating performance data has been taken largely from empirical data averages and thus represents what can be expected under typical or normal range environmental conditions. An inflation factor of 5 percent per year was utilized to update those costs not reported in 1973 dollars.

Other major assumptions which were utilized in order to develop the cost and quantity figures reported in the profile sheets are:

- Daily flows were estimated to average 100 gpcd.
- Medium strength sewage was utilized as characterized in Table III.
- A uniform land value of $1000 per acre was assumed for all related wastewater treatment plant operations (i.e., land for plant facilities, liquid effluent application land requirements, sludge application land requirements, etc). The land cost per treatment strategy appears under a separate heading on the profile sheets and, therefore, the land impact upon the total cost of the strategy can be easily ascertained.
- The liquid effluent transportation distance from the treatment plant to the irrigation field was assumed to be negligible (1/2 mile), whereas, the sludge transport distance depends upon the type of disposal and size of the plant.
- Truck transportation was assumed for land application of sludges for plant capacities of equal to or less than 10 MGD and pipeline for larger plants. Round trip truck hauling distances for plants less than or equal to 1 MGD were assumed to be 20 miles. A round trip hauling distance of 50 miles was assumed for plants in the size range 1 to 10 MGD. Pipeline transportation was assumed to consist of laying pipe through 25 miles of suburban lands and 25 miles of rural lands.

- Transportation of sludges for ocean disposal was assumed to be achieved by barging for plants with capacities of 10 MGD or less or equal to and by pipeline for larger plants. The barge hauling distance was assumed to be 100 miles round trip. On the other hand, pipeline transport of the sludge slurry was assumed to invoke 5 miles of rural land and 80 miles beyond the coastline. The ocean outfall line included a special concrete outer lining for negative buoyancy and an inner liner for saltwater corrosion protection.

APPENDIX C

THE AGRICULTURAL ASPECTS OF LAND DISPOSAL OF SEWAGE AND SEWAGE SLUDGES

APPENDIX C

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APPENDIX C

THE AGRICULTURAL ASPECTS OF LAND DISPOSAL OF SEWAGE AND SEWAGE SLUDGES

SUMMARY AND CONCLUSIONS

Sewage sludge does not compare favorably with commercial fertilizers when the comparison is based solely on nutrient content or ease of handling. Sludges may contain pathogenic bacteria and/or heavy metal concentrations which will potentially limit their use on cropland. On the other hand, sewage sludge does have exceptional soil conditioning characteristics which greatly enhance soil physical fertility. This property may be of real economic value when marginal lands are being reclaimed for agricultural or silvicultural purposes.

To achieve widespread acceptance by farmers, it may be necessary to enrich and further process sludge to a form which is easy to use. This type of processing will add to the cost of the final product so that incentives may have to be created to induce fertilizer processors to incorporate sludge into their products. Subsidies to processors may be required to make their efforts worthwhile. In any case, municipalities should evaluate both the potential for elimination of costly disposal altneratives and the potential for better resource allocations when considering ultimate disposal of sewage sludges on cropland.

Effluent water from sewage treatment facilities may be valuable for irrigation uses. While the value of irrigation water is typically quoted as $12-$60 per acre foot, the potential for reducing demands on higher quality water for other uses suggests an even greater potential value. Additionally, up to $6.88 of nutrients may be present in an acre foot of primary clarified effluent. At typical irrigation levels of 40-48 inches of water per year, the nutrients present in wastewater effluents could reduce the need for additional fertilization. Potential problems from pathogenic organisms and the concentration of heavy metals must be determined for the irrigation use of wastewaters just as in the case of spreading of sewage sludges.

Technological improvements for handling and spreading sewage sludge and effluent waters will potentially increase the value of these materials both by lowering associated application costs and by minimizing aesthetic objections.

The following major conclusions were drawn as a result of this study.

- Sewage sludge cannot compete with commercial fertilizers when comparison of the two is based on macronutrient content alone.

- Use of sewage sludge on land which has been intensively farmed would return valuable organic material to the soil. Organic material enhances soil physical fertility and is, therefore, beneficial.

- Sludges may contain pathogenic organisms and/or concentrations of heavy metals at levels which could have harmful effects on crops or ultimate consumers.

- Difficulties associated with the application of sludge and the bulk quantities of sludge which must be handled to achieve desired nitrogen loadings will lower the net value of sludge to the farmer as a fertilizer.

- In some instances, there are local markets for organic sludge produced from specific municipal treatment facilities.

- Where a market for sludge does exist, price must be based on the prevailing price of commercial fertilizer and on the difference in hauling and spreading costs.

- Added incentives may be necessary to attract widespread acceptance and use of sludge as a fertilizer material.

- Widespread use of sludge as a fertilizer could potentially satisfy two percent of the current artificial fertilizer market.

- Spray irrigation of wastewater treatment plant effluents is a viable method for disposing of water and/or irrigating land.

- Effluent water for irrigation may exceed its value purely as agricultural water due to the potential for replacing higher quality water presently used which could then be employed for higher use purposes. Nutrients in primary treated effluent water may increase the value of that water and in some cases could reduce or eliminate the need for commercial fertilizers.

- Potential problems from pathogenic organisms, heavy metals, and other toxic materials present in effluents must be considered though they are likely to be less severe than those associated with spreading of sewage sludge.

- The irrigation equipment industry is actively interested in effluent irrigation applications and has begun to offer technical improvements in the market.

GENERAL

Continuing efforts to reduce environmental degradation related to wastewater disposal, and an increasing desire to gain more efficient use of resources has stimulated renewed interest in the land application of municipal wastewater and sludges. In particular, efforts are being directed to dispose of wastewater through spray irrigation and waste sludges through land spreading. Before one can evaluate these alternative treatment strategies and compare them to other existing courses of action, one must gain some insight into the potential benefits which might be gained from land application as well as the potential stumbling blocks. The following discussion is directed to this task. Pertinent information is divided into that dealing with sludge and that pertaining to wastewater treatment plant effluents. These two materials represent the products, as it were, of a municipal wastewater treatment plant.

Prior to a discussion of these factors, however, it is important to define the context within which the evaluation is to be made. Clearly, issues of both a technical and an economic nature must be discussed. The technical aspects relate to the physical-chemical properties of the sludge and effluent waters and the ease with which they can be applied to soil at the appropriate concentration. The economic aspects relate both to waste treatment as a necessary service, and the waste treatment products as potential assets to agricultural operations. Sludge is a byproduct produced during the performance of a service--wastewater treatment. Hence, the economics of an alternate sludge disposal strategy, namely land spreading as a fertilizer compound, cannot be evaluated solely within the traditional context of a product-generating project. Whereas product considerations often focus on profit maximization, sludge disposal is typically viewed as a cost minimization problem. Similarly, effluent water must be treated prior to discharge. With this in mind, the sewage treatment plant is not directly analogous to a profit maximizing firm.

While a traditional profit maximizing firm will attempt to equate marginal revenue with marginal costs to obtain maximum welfare, additional considerations are necessary for sewage treatment facilities. Marginal costs are positive and marginal revenues are generally negative. In a situation where a traditional firm would cease to exist, a sewage treatment facility is kept in business by the community that depends on its service. The service nature of the sewage treatment plant must ultimately be a part of a complete economic analysis of sludge and effluent water. Both effluent water and sludge, as opposed to traditional products, may be negative priced products. The implications of replacing costly disposal processes must therefore be analyzed and compared with potentially less costly reuse alternatives.

The use of sewage sludge as a fertilizer material is not a new concept. Successful application of sewage to the land has been practiced for decades throughout the world. Digested sludge has been applied to more than 2000 acres of land in Maple Lodge, England since 1952. Similar operations were initiated at Miami, Florida in 1956. In Las Vegas, Nevada, where sludge is employed to develop park and recreational areas, demand has outstripped supply.[80] However, such disposal operations are not universally acceptable either from an economic or an environmental point of view. Indeed, Carlson and Menzies[81] of the Soil and Water Conservation Research Division of the U. S. Department of Agriculture note that:

> *"It has long been an article of faith among city dwellers that almost any form of waste, with proper composting and processing, can be made into a fertilizer that farmers will gladly pay for. They reason that even if it does not contain much of the essential plant nutrients, surely it will improve soil structure and produce healthy plants. This is simply not true; at least not true enough to persuade the modern commercial farmer. The present-day farm manager is an astute businessman, and he will first ask 'What will it cost me to put this on the land per pound of available N, P, and K?', and then 'Does it contain substances that will harm my soil or reduce the value of my crops?'"*

SEWAGE SLUDGE

The objective of this effort is to thoroughly assess the factors and conditions which tend to favor or limit the use of sewage sludge as a fertilizer and to compare sewage sludge with commercial fertilizers. In carrying out an analysis of the fertilizer value of sewage sludge, several major factors must be studied as listed below.

- Macro- and micronutrient content of sludges.

- Beneficial effects of sludge organic content.

- Potential health hazards associated with use of sludge as a fertilizer.

- General acceptability of sludge fertilizer to the potential user.

- Economics of fertilization with sludge.

Nutrient Value

Growing plants require a great many macro- and micronutrients to sustain normal growth over a given life cycle. Three macronutrients: nitrogen, phosphorus, and potassium; are generally supplied in fertilizer formulations to increase the yield of a given area. It is a fact that sludges from domestic wastewater treatment plants contain these macronutrients as well as many micronutrients beneficial to plant growth.

Peterson, Lue-Hing, and Zenz have compiled a chemical analysis of sewage sludges from various wastewater treatment plants in the United States.[82] These data are presented in Table C-1. The average nitrogen (N), phosphorus (P), and potassium (K) contents of sludges from the seven facilities are 5.10 percent, 2.33 percent, and 2.37 percent, respectively.

The data in Table C-1 encompass a wide range of sludge types: primary in Georgia, and primary plus waste activated at the facilities in Minnesota, Colorado, and Illinois. There was no sludge treatment in St. Paul. The West-Southwest Illinois plant of the Metropolitan Sanitary District of Greater Chicago (MSDGC) included $FeCl_3$ conditioning vacuum filtration, and heat drying of waste activated sludge. The sludge treatment at the two other Illinois facilities included anaerobic digestion of primary plus waste activated sludges without supernatant drawoff. The Hanover sewage is primarily from domestic sources, while the Calumet and West-Southwest sewage is a 3:2 blend of domestic and industrial material.[82]

Analyses of the data in Table C-1 indicate that in each type of sludge, nitrogen is the predominant nutrient available. The phosphorus and potassium contents in each case are low and may be insufficient for some cropping systems. For these systems, sludges are incomplete fertilizers. This implies that application of sufficient sludge to completely supply the nitrogen requirements of these cropping systems will not fulfill their phosphorus and potassium requirements. In such cases, either additional commercial fertilizer must be supplied in a second application, or the phosphorus and potassium must be supplemented prior to application. Supplementation is technically feasible and has been carried out successfully in certain instances.[83-86] However, this may represent a major additional cost.

TABLE C-1

CHEMICAL ANALYSIS OF SEWAGE SLUDGES IN PERCENT · DRY WEIGHT BASIS FOR SEVEN LOCATIONS[82]

Nutrient	Hastings, Minnesota	St. Paul, Minnesota	Hanover, Illinois	Calumet, Illinois	West-Southwest, Illinois	Denver, Colorado	Athens, Georgia
N (Total)	5.84	4.69	5.57	5.20	6.37	4.57	3.5
N (NH_3)	2.34	1.33	3.63	2.40	trace		
P	2.61	2.20	2.59	3.90	2.49	1.75	0.75
K	0.27	0.24	0.68	0.55	0.41		0.22
Ca	2.97	2.52	5.05	4.20	1.4	7.38	1.21
Mg	0.26	0.40	1.64	0.60	0.75	0.45	0.09
Zn	0.075	0.14	0.069	0.35		0.172	0.252
B	0.0013	0.002			0.002-0.04	0.00022	0.00199
Fe	0.45	0.76	2.22	3.68	5.32	1.48	
Mn	0.015	0.039	0.07	0.14	0.012	0.0253	0.0199
Al	0.65	0.74		1.21			
Cd	0.00079	0.036	0.0089	0.0125	0.028		
Cl			0.12	0.74			
Cr	0.390	0.067	0.019	0.112	0.362		
Cu	0.12	0.065	0.062	0.088	0.11	0.0324	0.046
Ni	<0.001	0.015	0.032	0.020	0.034		0.0026
Pb	0.039	0.070	0.083	0.18	0.141		

In other studies, Fair and Geyer,[217] Anderson,[103] and Davis[104] have summarized nutrient levels for sludges resulting from various treatment strategies as presented in Table C-2. In general, activated sludges contain more nitrogen than primary or trickling filter sludges. Digestion causes solubilization of 40-50 percent of the nitrogenous materials (as ammonia) as well as 8-10 percent of the phosphorus. Wet oxidation solubilizes all of the nitrogenous materials, but has little effect on the phosphorus. Imhoff digestion and sand drying are similar to conventional digestion in effects on nutrient levels. Heat drying has minimal effects on nutrient loss.

Other sludge treatment processes will affect nitrogen and phosphorus levels in similar ways. Anaerobic biological systems typically convert nitrogen to soluble ammonia and hence sponsor return of nitrogen in process supernate. Aerobic biological systems may convert soluble ammonia to nitrates. Physical-chemical oxidation processes can be quite complete, generating nitrate-nitrogen in the process supernate. Phosphorus levels will not be grossly affected, but may be reduced somewhat through biological solubilization. Use of conditioner chemicals such as ferric chloride or lime will bind the phosphorus in the sludge solids.

Hence the macronutrient levels in sludges will vary both with the source of the wastes, and the treatment processes to which the wastewater and sludges have been subjected. These macronutrient levels, however, represent maximum potential values and not necessarily available levels. This is an important point in comparing sludges with commercial fertilizers. Whereas commercial formulations have a guaranteed level of biologically available nutrients, organic sludges may include nitrogen and phosphorus forms which are inaccessible to plants and bacteria. For instance, Morris reports the availability of nitrogen, phosphorus, and potassium in cattle manure to be 50, 67, and 75 percent, respectively.[144] This suggests that sludge fertilizer values based on total macronutrient content may well be overstated.

Sludges may also have economic value based on their micronutrient content. The use of micronutrients is a more precise operation in agronomy than the use of nitrogen, phosphorus, and potassium. Consideration of the value of micronutrients in the estimation of fertilizer potential by state could be spurious. However, some appreciation for the magnitude and spatial dimension of this market can be seen from Table C-3. Typically, micronutrient requirements are limited, and specific to particular locations. Dean notes that many soils have no need for micronutrients.[141]

TABLE C-2

NUTRIENT COMPOSITION OF SLUDGES RESULTING FROM VARIOUS TREATMENT ALTERNATIVES

	Raw Sludge Makeup		Product Sludge Makeup		
Treatment Type	% N	% P_2O_5	% N	% P_2O_5	Reference
Primary Treatment (national average)	0.8-5.0	1.0-3.0			
Digested Primary (Washington, DC)	2.41	1.12	3.06	1.44	103
Trickling Filter Humus (national average)	-	-	1.5-5.0	-	217
Activated Sludge (national average)	-	-	3.0-10.0	-	217
Activated Sludge (average 1931-1935)	-	-	6.0	3.2	103
Digested Activated Sludge (average 1931-1935)	-	-	2.2	2.1	103
Activated Sludge (average 1951-1955)	-	-	5.6	5.7	103
Digested Activated Sludge (average 1951-1955)	-	-	2.4	2.7	103
Activated Sludge (Baltimore, MD)	2.23	1.29	2.36	11.01	103
Activated Sludge (Jasper, IN)	2.90	1.62	3.51	2.81	103
Activated Sludge (Richmond, IN)	3.8	5.19	3.02	3.64	103
Activated Sludge (Chicago, IL)	2.7	2.71	4.98	5.58	103
Activated Sludge Humus Tank Sludge (Baltimore, MD)	2.23	1.29	5.34	3.96	103
Heat Dried Activated Sludge (Baltimore, MD)	2.23	1.29	3.05	2.97	103
Digested Activated Sludge (Jasper, IN)	2.90	1.62	5.89	3.49	103
Digested Activated Sludge (Richmond, IN)	3.8	5.19	2.24	4.34	103
Heat Dried Activated Sludge (Chicago, IL)	2.7	2.71	5.56	6.56	103
Wet Air Oxidized and Lagooned Activated Sludge (Chicago, IL)	3.78	0.98	0	1.72	104
Imhoff Digested and Soil Dried Activated Sludge (Chicago, IL)	2.11	1.87	1.82	1.75	104
Digested and Lagooned Activated Sludge (Chicago, IL)	5.09	2.90	5.17	3.61	104

TABLE C-3

TONS OF MICRONUTRIENTS SOLD FOR FERTILIZER IN THE UNITED STATES BETWEEN JULY 1971 AND JUNE 1972[96]

	Copper	Iron	Manganese	Zinc	Molybdenum
New England	13.0	.6	5.1	119.5	
Mid-Atlantic	58.4	50.3	194.9	574.3	.4
South Atlantic	426.6	308.4	5,455.0	2,674.3	24.7
East North Central	31.9	202.6	5,030.0	3,590.7	32.5
West North Central	36.1	188.0	779.8	3,359.0	8.3
East South Central	5.0	24.1	67.5	1,100.9	12.5
West South Central	16.8	215.6	186.8	1,052.4	20.7
Mountain	5.2	143.4	254.6	1,402.9	.2
Pacific	22.2	200.6	383.2	1,979.4	2.7
United States	615.2	1,333.7	12,356.9	15,853.4	102.0

Sludge Organic Content

In addition to containing chemical elements which are necessary for growth, sludge may enhance plant growth through amendment of soil properties resulting from organic constituents present in the sludge. This action may proceed via several principal mechanisms:

- Moisture-holding capacity,
- Mulching ability which reduces or eliminates erosion by wind or rain,
- Improvement in tilth,
- Improvement in soil structure and aeration, and proper relationship of voids to solids,
- Reduction in leaching out of nutrients and pesticides, and
- Good physical structure for the development of desirable soil microorganisms and larger organisms such as earthworms.

An important property attributable in part to the organic content of soils is the cation exchange capacity (CEC). Cation exchange is important because it limits the leaching of plant nutrients from the soils by sorbing these materials on the solid phase. The organic content of a soil may account for up to one half of the cation exchange capacity of the soil. Sludges may enhance the CEC of a soil when added if they have that property in excess of that residual in the soil itself.

Of primary importance in soil conditioning is organic matter which consists mainly of humus or humic constituents. These substances decompose slowly and are valuable in light, sandy, or rocky soil, and in heavy clay. Plants require both moisture and air in the soil for best growth. Sandy soils have too low a "field (moisture) capacity," whereas clay soils tend to limit water infiltration and have insufficient macro-pore space for proper proportions of moisture and air. Sludge addition provides organic material which is degraded to humus by organisms in the soil. Humus improves both soil aeration and moisture-holding capacity and thus improves fertility. However, it should be emphasized that only a small portion of U. S. prime agricultural soils fall into either the sandy or clay categories, and thus this property is somewhat limited in value when considering U. S. agriculture as a whole.

The organic content of well digested sludge provides a substrate for the growth of desirable soil organisms and as the organic matter decomposes, nutrients are slowly made available for plant growth. Important nutrients in this category include phosphorus, sulfur, and nitrogen.

Well digested sludge has a large proportion of agglomerated particles which can benefit soil. Sludge particles also contain materials with chelating properties which help catch and chemically hold fine soil particles and minerals or salts, forming additional agglomerated particles. When tilth is improved with sludge, the soil provides for better root penetration and is easier to plow or till. Table C-4 summarizes the organic composition of sludges.

TABLE C-4

COMPOSITION OF SLUDGES*[87]

Constituent	Fresh Solids (%)	Activated Sludges (%)	Digested Sludges (%)
Organic matter	60-80	65-75	45-60
Total ash	20-40	25-38	40-55
Insoluble ash	17-35	22-30	35-50
Pentosans	1.0	2.1	1.5
Grease and fat (ether-soluble matter)	7-35	5-12	3.5-17
Hemicelluloses	3.2	--	1.6
Cellulose	3.8	7.0*	0.6
Lignin	5.8	--	8.4
Protein	22-28	37.5	16-21

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*Includes lignin

Biological properties which are difficult to quantify in terms of nutrient content have been attributed to sewage sludge. The value of these can be measured in terms of crop response to known quantities of organic solids. In 1963, Bunting concluded from more than 100 field experiments conducted in England that effectiveness of various composts and manures depended largely upon their content of plant nutrients.[99] Five years later, Hortenstine and Rothwell found gross effects of nutrients in compost to be similar to those from application of chemical fertilizers.[100] The pot experiments conducted by Allen, Terman, and Soileau with corn on a soil very low in available N showed that the compost made from garbage and sewage sludge solids would need to be supplemented with N fertilizer for positive yield effects to be obtained. Corn utilized P and K in the compost much more effectively than the N content.[94]

Duggan, Terman, and Mays evaluated heavy applications of compost made from municipal refuse and sewage sludge for production of forage sorghum, common bermudagrass, and corn. Positive yield responses were observed to annual compost application at rates up to 80 metric tons per hectare on bermudagrass, 143 metric tons per hectare on sorghum, and 112 metric tons per hectare on corn. However, the highest yields of bermudagrass or sorghum attained from compost application were equaled or surpassed by the application of commercial fertilizer at a rate of 180 kg/ha of N and adequate P and K. Over a two year period, compost significantly increased the soil's moisture-holding capacity, pH, organic matter, K, Ca, Mg, and Zn.[98]

On the basis of these agronomic experiments, it is concluded that while there may be some benefits derived from the use of organic solids over chemical fertilizer of an identical nutrient content, there are not sufficient differences to warrant consideration in the estimation of economic value of sludges.

Potential Harmful Effects

The use of sewage sludge on soils involves potential public health hazards which must be considered. Pathogens can potentially be recycled back to man through several mechanisms: 1) direct contact in the field, 2) transmission in a food crop, 3) infiltration to ground water, or 4) runoff to surface water supplies.

Little is known about the first two pathways. Most states prohibit use of sewage plant effluents on root or ground crops and many restrict use to crops for non-human consumption such as feed grains. Much of the data gap results from uncertainties as to the exposure-response relationships that exist. Whereas a single pathogenic organism may sponsor ill effects, in many cases, exposure to greater numbers will evoke no response. Until definitive work is done in this area, there will always be a degree of uncertainty as to the relative safety of land spreading practices.

It is known that the retention and accumulation of viable pathogenic organisms in the soil matrix will depend on moisture content, temperature, textural and organic characteristics of soil, aerobic or anaerobic conditions, and the activity of competitive microbial communities.[1] The environment appears to be unfavorable for growth and transmission of pathogens. McGauhey and Krone report results of studies by other investigators which suggest a maximum longevity of one month.[105] Rudolfs, on the other hand, reports viability may persist from a few hours to several months.[109] Data on survival times for pathogens in various media are given in Table C-5.

More specific work at the National Environmental Research Center in Cincinnati determined that Escherichi coli survived for at least 21 weeks after a single springtime sludge application to Pennsylvania fields. Pseudomonas aeruginosa and salmonella species proved less hardy. All species survived longer during the winter months.[110]

Infiltration should not pose a problem unless groundwater levels are quite near the surface. Reed, et al., suggest that five feet or more of soil column should provide adequate protection of ground waters. Water percolating through such a column will quickly be stripped of bacteria and virus.[1]

Surface water runoff problems are not expected to be acute. The major time for concern would be soon after application. Good planning and field design should provide for adequate control through entrapment of rainfall runoff prior to contact with surface waters. Such measures would alleviate any problems with pathogenic contamination.

In summary, insufficient exposure-response data has been generated to adequately describe pathogenic health hazards from land spreading of sludges. Until such information becomes available, a potential health hazard must be assumed. Hence sludges should be disinfected or composted prior to use.[10] Dotson has suggested there are several methods for destroying pathogens in sludge:[71]

- Long term storage,
- Pasteurizing at 70°C for 30 minutes,
- Adding lime to raise the pH to 11.5 or higher and maintaining the pH at about 11.0 for 2 hours or more,
- Using chlorine to stabilize and disinfect sludge (the effects of the residue on soils have not been determined), and/or
- Adding other chemicals.

Digestion or stabilization is also an important prerequisite for untreated raw primary sewage sludge because of the detrimental

TABLE C-5

SURVIVAL TIMES OF PATHOGENIC MICROORGANISMS IN VARIOUS MEDIA

Organism	Medium	Type of Application	Survival Time
Ascaris ova	soil	not stated	2.5 years
	soil	sewage	up to 7 years
	plants & fruits	AC*	1 month
Cholera vibrios	spinach, lettuce	AC	22-29 days
	cucumbers	AC	7 days
	non-acid vegetables	AC	2 days
	onions, garlic, oranges, lemons, lentils, grapes rice & dates	infected feces	hours to 3 days
Endamoeba histolytica cysts	river water	AC	8-40 days
	soil	AC	8 days
	tomatoes	AC	18-42 hours
	lettuce	AC	18 hours
Enteroviruses	roots of bean plants	AC	at least 4 days
	soil	AC	12 days
	tomato & pea roots	AC	4-6 days
Hookworm larvae	soil	infected feces	6 weeks
Leptospira	river water	AC	5-6 days
	soil	AC	15-43 days
Salmonella typhi	dates	AC	68 days
	harvested fruits	AC	3 days
	apples, pears, grapes	AC	24-48 hours
	strawberries	AC	6 hours
	soil	AC	74 days
	soil	AC	70 days
	soil	AC	at least 5 days
	pea plant stems	AC	14 days
	radish plant stems	AC	4 days
	soil	AC	up to 20 days
	lettuce & endive	AC	1-3 days
	soil	AC	2-110 days
	soil	AC	several months
	lettuce	infected feces	18 days
	radishes	infected feces	53 days
	soil	infected feces	74 days
	soil	AC	5-19 days
	soil	AC	70-80 days
	cress, lettuce & radishes	AC	3 weeks
	lake water	AC	3-5 days
Salmonella, other than typhi	soil	AC	15-70 days
	vegetables	AC	2-7 weeks
	tomatoes	AC	less than 7 days
	soil	sprinkled with domestic sewage	40 days
	potatoes	"	40 days
	carrots	"	10 days
	cabbage & gooseberries	"	5 days
Shigella	streams	not stated	30 min - 4 days
	harvested fruits	AC	minutes - 5 days
	market tomatoes	AC	at least 2 days
	market apples	AC	at least 6 days
	tomatoes	AC	2-7 days
Tubercle bacilli	soil	AC	6 months
	grass	AC	14-49 days
	sewage	?	3 months
	soil	?	6 months

*AC = Artificial Contamination

effects to soil and plant growth associated with sludge structure and grease content. Unfortunately, digestion or composting reduces nitrogen content by as much as 40-50 percent through solubization.[88] Some of this loss can be avoided through application of digester supernate along with the digested solids.

In addition to pathogenic organisms, sludges may contain excessive concentrations of heavy metals which could threaten public health. The variable and not insignificant concentration of heavy metals in sludges is shown in Table C-6. Similar values for digested sludge are given in Table C-7.

Little is known of the fate of heavy metals in soil. Jenne[90] proposed that the principal factor in retention of the heavy metals is sorption on hydrous oxides of manganese and iron. Metals are also complexed by organic matter present in the soil. It is expected, therefore, that there will be little migration in the soil. Nevertheless, the capacity of the soil to retain these elements is limited and eventual heavy metal breakthrough to the groundwater must be considered when using sludge as a fertilizer. Work with spray irrigation of wastewater, however, suggests that phosphate saturation may terminate activities before heavy metal saturation.[1] Additionally, soils can be limed to increase metal holding capacity. They may especially be necessary in some crops such as alfalfa which have a propensity to raise the acidity of soils.

Heavy metal buildup in soils can potentially be detrimental in two ways: 1) high levels in soils can inhibit or damage plant growth, or 2) heavy metal concentrations can be transferred into plant tissue where they may become a threat to human or animal consumption.

Continued buildup of heavy metals in the soil over long time periods can eventually reduce the productivity of soils and, thus, cancel the original intent of the sludge spreading operation. In 1959, Lunt found that the municipal sludge of West Haven, Connecticut more than doubled spinach yields and more than tripled table beet yields. However, industrial sludge from Tarrington, Connecticut reduced spinach yields due to the high copper and zinc content. The toxicity was accentuated when extra nitrogen was used but was corrected when the soils were limed. The total salts in sewage sludge delayed seed germination on the high level treatments.[91]

Weber[107] reports that zinc, copper, and nickel are the three metals of principal concern. Since all three display increased toxicity at low pH values, their concentration is expressed in zinc equivalent. To determine this value, copper is considered twice as toxic as zinc, and nickel eight times as toxic as zinc. Using this scale, Weber calculates that 250 mg of zinc equivalent

TABLE C-6

CONCENTRATION OF METALS IN SLUDGES[106]
(mg/g)

	Tahoe	Dayton	Little Miami Cincinnati	Mill Creek Cincinnati	Lorton VA	Indianapolis Plant 1	Barstow
	7/15/71	8/25/71	8/20/71	6/20/71	8/5/71	8/23/71	7/20/71
Ag, Silver	0.27	0.36	0.03	n.d.	n.d.	n.d.	0.05
Al, Aluminum	13.2	12.5	8.8	32.2	4.4	5.2	16.2
Ba, Barium	3.0	3.0	0.7	n.d.	0.7	1.3	1.5
Be, Beryllium	n.d.1/	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cd, Cadmium	0.18	0.8	n.d.	n.d.	0.17	0.24	0.58
Co, Cobalt	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cr, Chromium	1.0	5.9	1.7	1.8	0.4	2.6	0.5
Cu, Copper	1.3	6.0	2.3	1.6	0.9	2.0	1.7
Fe, Iron	8.7	20.4	16.0	13.2	27.4	15.3	10.6
Hg, Mercury	4.5*	n.a.2/	n.a.	n.a.	3.0*	n.a.	5.5*
Mn, Manganese	0.6	1.1	1.2	0.6	0.5	0.6	0.18
Ni, Nickel	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pb, Lead	2.8	6.9	2.0	2.7	1.1	2.8	0.8
Sr, Strontium	0.51	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
V, Vanadium	n.d.	n.d.	n.d.	1.6	n.d.	n.d.	2.1
Zn, Zinc	1.6	8.4	7.8	4.7	0.4	1.2	1.4

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* - micrograms/g
1 - n.d.: not detected
2 - n.a.: not analyzed

TABLE C-7

HEAVY METAL CONTENT OF DIGESTED SLUDGE[89]

Heavy Metal	Stickney, IL (mg/l)	Calumet, IL (mg/l)	Toledo, OH (mg/l)
Aluminum	--	--	1,800
Cadmium	9	1	--
Chromium	80	50	125
Lead	20	90	375
Manganese	5	13	300
Nickel	12	2	--
Zinc	150	90	500

per kg of soil could be spread over a thirty year period if soil pH is maintained above 6.5. In looking at both rural and industrial community sludges from England and Wales, Berrow and Weber found concentrations of zinc up to 3000 mg/l on a dry weight basis quite common. At an annual application of 10 tons per acre over a seven year period, soil zinc content would rise to a level above the maximum of the normal range in soils.[108]

The second detrimental effect resulting from heavy metals in sludge involves potential concentration of heavy metals in the tissue of plants grown on land which has been subjected to sludge spreading. Public health hazards could result directly from ingestion of vegetables, fruits, or grains on this land or indirectly from ingestion of meat from animals which have grazed on the land. Further research is needed concerning the toxicity of heavy metals to plants and on the human and livestock intake through the food chain resulting from concentration of heavy metals in plant tissues.[92]

Studies with cornfields in England suggest that the quality of product feed is not impaired through use of various sludge application rates. The leaf and grain metal concentrations are presented in Table C-8 as reported by Hinesly, et al.[111]

Van Loon[112] on the other hand reports that cadmium and lead have been found in sufficient concentrations to be assimilated into

TABLE C-8

HEAVY METAL CONCENTRATIONS IN CORN GROWN IN SLUDGE ENRICHED SOIL[111]
(ppm oven dry basis)

Rate of Sludge Application (inches per week)	Zinc	Copper	Nickel	Cadmium
LEAF:				
0	58.0	8.9	2.8	3.3
1/4	85.0	9.0	1.3	3.0
1/2	137.8	10.2	2.6	5.3
1	212.0	8.7	4.3	11.6
GRAIN:				
0	88.8	5.2	2.28	0.30
1/4	93.0	6.3	3.03	0.60
1/2	127.0	5.2	2.18	0.79
1	152.3	5.6	3.08	1.03

good crops at harmful levels. Processed sewage sludge contained up to 63 ppm cadmium and 447 ppm lead. Sludge produced during fall and winter may contain even higher concentrations. Kobayashi[113] and others found that when cadmium was present in soil at a level near 0.003 percent Cd, whole wheat grain would contain more than the 13 ppm maximum cadmium level allowed by the Food and Drug Administration. Detailed data are presented in Table C-9.

Similarly, John, et al.,[114] found that cadmium concentrations in crops readily exceeded allowable levels when the amount of exchangeable cadmium in the soil was high. Organic soil content decreased the exchangeable amounts while soil acidity increased them.

A great deal of work remains to be done to clarify these interactions. The soil chemistry and associated interactions of various metals are very complex. Hinsely, et al.,[115] have confirmed that synergistic and antagonistic interactions between metals affect both their uptake and translocation in plants. Much of the work done in the past in this area has focused on nutrient cultures or sandy soils. These represent the complicated soil matrix to which most sludges will be added, and hence do not reflect many of the interactions which will be most important in determining phytotoxicity and bioconcentration of heavy metals.

TABLE C-9

CADMIUM LEVELS IN RICE AND GRAIN RESULTING FROM RESIDUAL LEVELS IN SOIL[113]

Concentration of CdO in Soil (%)	Concentration in Rice Polished (ppm Cd)	Concentration in Rice Bran (ppm Cd)	Concentration in Wheat Whole Grain (ppm Cd)
0	0.16	0.59	0.44
0.001	0.28	0.79	8.27
0.003	0.40	0.84	15.5
0.01	0.78	1.60	29.9
0.03	1.37	2.68	41.4
0.1	1.62	2.94	60.7
0.3	1.94	3.19	48.6
0.6	1.73	3.94	90.8
1.0	4.98*	-	139.0

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* Unpolished

Factors Affecting General Acceptance of Sludge Use

Factors other than its limited fertilizer value which could impair the use of sludge for agricultural purposes are related to ease of use.

Farmers often employ liquid fertilizer solutions for bulk application on crops. This form of nutrient enrichment allows rapid distribution of concentrated macronutrients. Application of sewage sludges is more difficult because of the high solids content of the material and the dilute nature of the nutrients. Application of sludge has considerable drawbacks even in competing with solid fertilizers. For example, to apply 100 pounds of N a farmer would need to apply only 217 pounds of urea (46% N) compared to nearly 40,000 pounds of liquid sludge (.25% N). Similar considerations have long plagued the use of animal manure as a fertility additive and soil builder. Use of the solid waste materials requires more time and expense. Further advances in application technology are required to reduce the economic impact of these considerations.

Municipalities committed to use of sludge for agricultural purposes could potentially minimize the negative aspects of many of these acceptance factors by extending additional services to the farmer. These might include free delivery of sludge to the application site and low cost leasing of specialized application equipment. Whereas it may not pay for the farmer to maintain the required equipment for his won use, the city could recover costs with year-round leasing to the various participating land owners.

ECONOMIC VALUE OF SLUDGE

The content of nitrogen, phosphorous, and potassium of a fertilizer is usually of primary concern to the farmer. If organic solids are to compete on the basis of macronutrient content, they must be priced competitively with commercial fertilizer. The average price per dry ton of nutrient calculated on the basis of the most commonly used form of each nutrient is presented in Table C-10. The average U.S. price was $99, $393, and $118 per ton of N, P, and K, respectively. On the basis of these prices, the macronutrient value of the organic solids is $14-15/dry ton.

Considerable disparity in this value will exist among regions of the United States. The nutrient content of the organic solids varies from one treatment facility to the next as can be seen from Table C-1. There are also considerable differences in soil requirements in different parts of the country.

Since organic solids are bulky, it is necessary to consider the cost of transporting the material to the farm. The cost of hauling a 20-ton load is $0.34/ton for the first three miles and $0.10/ton per mile for additional distances.[93] If a farm were located ten miles from the treatment facility, the cost of hauling would be $1.04/ton. The cost of hauling the material 20 miles would be $2.04.

Depending upon the distance from the treatment facility to the farm gate, the net economical value of the organic solids would decrease if the farmer buys the solids at the treatment plant. For example, a farmer located ten miles from the site could pay $13.96-$14.96/dry ton for the material minus the difference in the spreading costs between sludge and commercial fertilizer. Located 20 miles from the facility, a farmer could afford to pay a dollar less. Whereas the added transportation costs and subsequent spreading costs may completely negate the value of the sludge to the farmer, it may be desirable to reduce these costs by providing for delivery of sludge to the farmer at no cost. This would constitute an easily operated form of subsidy. While it would raise processing costs for the treatment plant, it might still represent an overall cost saving since it would replace otherwise more costly alternatives.

TABLE C-10

AVERAGE PRICE IN DOLLARS PER TON OF NUTRIENT PAID BY FARMERS IN 1972[95,96]

Region	Nitrogen[a] (N)	Phosphorus[b] (P)	Potassium[c] (K)
New England	224	653*	151
Mid-Atlantic	225	646*	163
E. N. Central	97*	390	155
W. N. Central	94*	394	115
South Atlantic	201	490*	137
E. S. Central	189	407	131
W. S. Central	190	393	116
Mountain	119*	427	133
Pacific	133*	628*	135

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[a] Generally based on the price of ammonium nitrate. Asterisk indicates price of anhydrous ammonia used as base.

[b] Generally based on the price of 20.03% P. Asterisk indicates price of 8.7% P used as base.

[c] Based on price of nitrate of potash, 49.8% K.

The difference in the spreading costs may exceed the economic value of the sludge. In St. Mary's, Pennsylvania, the cost of hauling digested sludge 2.9 miles away and spreading it at four percent solids averaged $19.92 per ton of sludge solids. The operation employed a 1500 gallon tank truck to handle the wastes of the 1.3 MGD plant.[140] The 1972 costs for pumping and spreading 700 tons of dry solids in a six percent liquid slurry in San Diego, California were $10.57 per ton of dry solids.[142] Costs for other spreading operations are summarized in Table C-11.

The broad range in values, $5-$30 per dry ton reflects the economics between pipeline operations to nearby fields (relatively large plants) and trucking operations (smaller plants).

If pasteurization is required, an additional operating cost will be incurred. Triebel[143] estimates this cost will vary from $8.60 per ton of solids for 2.14 tons per day, to $1.30 per ton of solids for 27.4 tons per day.

Organic solids are now marketed under the brand names of Milorganite in Milwaukee, Wisconsin; Chicago in Chicago, Illinois; and Nitrohumus in Los Angeles, California. The Los Angeles firm sells about 50,000 tons per year. In bulk, material that is about 25 percent to 27 percent moisture sells for $12.50/ton or $6.30/yd delivered. The material is wholesaled in fifty pound bags for $0.83 and is then retailed for $1.39.[101] It is the consideration of the manager of the fertilizer company in Los Angeles that a fertilizer market could be developed for all of the sewage sludge that Los Angeles could produce. A stable supply of material is necessary however. It may be that this is a business in which profits are accrued to market development ability. If long term supplies are assured, it can be profitable to develop a market. Past experience indicates that such market development may indeed be a formidable task. Similar activities by commercial composting operations have met varying degrees of success. A number of composting plants in the U. S. have discontinued operations permanently.[102] Failure has largely been attributed to the inability to develop an adequate market.

On the other hand, operations at the Milwaukee sewage treatment plant have been quite successful. Milwaukee has marketed dried activated sludge under the trade name "Milorganite" for several years. The Milwaukee wastewater treatment authorities decided to set up facilities to completely produce and market the product and have been successful in their efforts. It must be noted, however, that dried activated sludge has a higher nitrogen content, up to six percent by weight, than normal digested sludge and is, therefore, more valuable as a fertilizer compound. Milwaukee sludge is also somewhat different than typical municipal sludges due to a high brewery waste content. Also, heat drying is an expensive process and one which most wastewater treatment plants cannot presently afford.

TABLE C-11

COSTS FOR LAND SPREADING OF DIGESTED SLUDGE IN THE U.S.[143]

Location	Approximate Plant Size (mgd)	Estimated Cost for Land Spreading of Digested Sludge (dollars per ton of solids)
New York, New York	--	$11.89
Chicago, Illinois	1300	26.02*
San Diego, California	90	10.57
St. Marys, Pennsylvania	1.3	19.92
Little Miami, Ohio (Green County)	1.5	22.00
Piqua, Ohio	3.8	17.50 to 30.00
Franklin Regional Wastewater Treatment Plant, Franklin, Ohio	4.5	5.00
Montgomery County (Dayton), Ohio		18.00 to 21.00

* Expected costs after construction of pipeline. Present costs using barge transportation are $62.32.

Dried digested sludge has also been sold or given away in many instances. The market for sludge in this form has traditionally been with home gardeners and, therefore, does not provide a solution for widespread ultimate disposal of sludges.

None of the above mentioned wastewater treatment plants presently marketing sludge are recovering their costs of production. Clearly, incentives may be needed if the widespread use of sludge on cropland is to be accepted. The conservation aspect will be enticing to some people who will use the sludge for idealistic reasons. Farmers, however, will require a product which has a balanced nutrient content and is easy to use.

The U.S. Department of Agriculture measures the consumption of natural organic fertilizers.[96] This classification includes animal wastes, oilseed byproducts, compost, dried manure, and sewage sludge. Almost 25 percent of that which is classified as natural organic fertilizer is sewage sludge. A regional summary of the estimated point demand for natural organic fertilizers in the U.S. is given in Table C-12.

TABLE C-12

ESTIMATED POINT DEMAND FOR ORGANIC FERTILIZERS BY REGION[96,97]

Region	Quantity (tons)
New England	56,056
Mid-Atlantic	198,715
E. N. Central	843,933
W. N. Central	2,476,113
South Atlantic	667,664
E. S. Central	553,342
W. S. Central	1,846,210
Mountain	2,361,269
Pacific	654,265
United States	9,657,587

Since sludge has a low inherent nutrient content and may require enrichment and processing to an easily usable form, in general it is unlikely that major fertilizer producers will be willing to buy sludge from the wastewater treatment plant. Therefore, profits should not be expected from the disposal of sludge in this manner. Two possibilities appear evident: the fertilizer producer could arrange to remove the sludge at no cost or he could be paid to remove the sludge. In either case, the fertilizer company receives a form of subsidy to compensate for eliminating further sludge disposal costs on the part of the municipality.

Similarly, farmers may be enticed to use larger quantities of sludge if delivery is provided as a free service provided by the sewage treatment authority to the farmer. This would eliminate one major cost factor against which farmers would weigh the relative merits of sludge fertilization to estimate the value of the practice to their particular operation.

On the basis of chemical, agronomic, and economic data, it is concluded that there could be a local market for organic sludge produced from a specific municipal treatment facility. The product must be analyzed for nutrient content. Department of Agriculture county agents or other agricultural specialists must be consulted to determine the relationship between the chemical content of the organic solids and the chemical requirements of the soil. Price must be based on the prevailing price of commercial fertilizer in the area and on the difference in hauling and spreading costs. If the material is supplied to a distributor, he must have a contract of sufficient duration to cover costs of market development.

POTENTIAL EFFECT OF SLUDGE USE ON COMMERCIAL FERTILIZER USE

In 1968, Hudson[218] estimated that the amount of dry solids produced per year from municipal wastewater treatment plants was eleven million tons. As a rule of thumb, digestion or composting reduces the total mass of the sludge organic material by thirty-five percent; therefore, based on Hudson's sludge production number of eleven million tons per year, 7.2 million tons of processed sludge would then be available for use on cropland. If the primary nutrient content of this material averaged two percent N and 1.5 percent P_2O_5, the sludge produced per annum would have total nitrogen and phosphorus contents of 144,000 and 108,000 tons, respectively.

Current annual consumption of nitrogen fertilizers in the United States is approximately eight million tons of N.[219] Consumption of phosphorus in commercial fertilizers is approximately five million tons per year.[88] At these consumption rates, the amount of N and P_2O_5 which could be supplied by using processed sludge would amount to only two percent of the current commercial fertilizer demand.

EFFLUENT WATER

Effluent water is used, among other ways, for cooling in industry, for groundwater recharge, for irrigation in agriculture, and for recreation. Industrial users generally require a fairly constant supply of water and actually consume a small portion of the water that they use. Texas uses more effluent water for industrial purposes than any other state.[118] A survey of industrial users of effluent water showed that more than 150 industries in 38 states reclaim industrial wastewaters and about 15 in 9 other states use municipal effluent water.[119] In 1959, it was reported by Connell and Berg[120] that industrial use of effluent water constituted approximately one percent of the total available and that the potential may be as high as 25 percent. In 1964, Connell and Forbes estimated that the total amount of effluent water approached 20 BGD and that over 40 percent of this total may be used by industry in the future.[121]

Literature describing the use of effluent water for groundwater recharge, and for the irrigation of city parks, gardens, and golf courses is available.[122,123] The estimate of the demand for effluent water presented here is based on its use in irrigated agriculture since this is perhaps the most widely accepted reuse alternative and results directly from use of spray irrigation as a wastewater treatment alternative.

Considerable research has been carried out at Pennsylvania State University over the past eight years on the use of effluent water for irrigation. However, the focus of this research has been to use the soil as a living filter for renovation and conservation of effluent water. Land area is minimized and water applied is maximized. Such practices will result in the lowest marginal value product attributed to the effluent water and the highest marginal value product attributed to the land. This approach understates the value of effluent water. In the 1963-1964 experiments, zero, one, and two inches of effluent water were applied per week.[124] The results of the experiments are presented in Table C-13.

Assuming an equal division of land planted to hay, corn, wheat, and oats in a farmer's rotation, the marginal value product of the first acre-inch of effluent water is $52.62. The marginal value product for the second inch is $5.94. These values are presented in Table C-14. Based on the values presented in Table C-14, there is considerable difference between the marginal value product of grain and hay. A marginal value of $88.86 could be expected from an acre-inch of effluent water to produce hay or $119.37 for two acre-inches. If grain were produced, a marginal value of $41.87 could be expected from an acre-inch of effluent water. However, if two acre-inches were used per acre, effluent water would be of lower unit value. This example clearly points out the relationship between commodities grown and quantities applied when estimating the value of effluent water.

From the analysis of the Pennsylvania State data, it is obvious that effluent water could have a positive value and that the value depends on both the amount applied to a unit of land and the crop to which it is applied. With an absence of appropriate data to measure the response of crops to alternative levels of effluent water in different locations, estimates of the value of natural water must be derived from research carried out in several states.

TABLE C-13

CROP YIELDS FOR THREE APPLICATION RATES OF EFFLUENT WATER AT PENNSYLVANIA STATE UNIVERSITY[124]

Crop	Year	0 Inches per Week	1 Inch per Week	2 Inches per Week
Red Clover Honey (tons of dry matter per acre)	1963	2.48	4.90	4.59
	1964	1.76	5.30	5.12
Alfalfa Hay (tons of dry matter per acre)	1963	2.18	3.73	5.12
Corn Grain (bushels per acre, 15.5% water)	1963	73.00	103.00	105.00
	1964	80.70	120.90	116.10
Corn Stover (tons per acre, field moisture basis)	1963	4.29	6.68	6.75
	1964	3.58	7.29	8.48
Wheat (bushels per acre)	1963	48.00	44.90	53.50
Oats (bushels per acre)	1964	82.40	124.50	97.00

TABLE C-14

MARGINAL VALUE PRODUCT OF AN ACRE-INCH OF EFFLUENT WATER, BASED ON THE 1963-64 PENNSYLVANIA STATE EXPERIMENTS AND AVERAGE PRICES RECEIVED BY FARMERS FOR HAY, CORN, WHEAT AND OATS, APRIL 15, 1973

Commodity	Price[96]	First Inch	Second Inch
Hay	$33.90/ton	+$88.86	+$30.51
Corn	$142/bu	+$99.68	-$ 3.97
Oats	$0.774/bu	+$32.59	-$21.28
Wheat	$215/bu	-$ 6.66	+$18.49
Average		$52.62	$ 5.94
Grain Average		$41.87	-$ 6.76

Ruttan[125] has pointed out that the demand for irrigation water can be treated either as derived from the demand for irrigated land or as derived directly from the demand for farm output. If irrigation water is regarded as a strict complement to irrigated land, it is appropriate to treat the demand for water as derived from the demand for irrigated land and specific irrigation water requirements. If, on the other hand, an independent output response can be obtained for irrigation water while holding the land input constant, the demand for irrigation water should be derived directly from the demand for farm output.[125] The problem of estimating the demand for water is that there exists for each location a range over which land, capital, labor, and water are substitutable factors of production.[126]

Bureau of Reclamation water charges are of little use in determining the value of irrigation water. The Bureau, under existing laws, prices agricultural water in accordance with the water users ability to pay, provided his ability is sufficient to pay certain assigned costs. Thus, charges in all areas are highly variable and are local in nature.

Nelson and Bush[127] conducted a study of the cost of procuring groundwater for irrigation in Maricopa and Pinal Counties in central Arizona. They estimated that the fixed, added capital, and variable costs of pumping groundwater from an average well depth of 949 feet was $12.26/acre-foot in 1963. It is assumed that the marginal value product of this water would be greater than $12.26/acre-foot.

Miller, Boersma, and Castle[128] calculated the value of irrigation water in the Willamette Valley. Bush bean and field corn producers were surveyed in the four county area of Marion, Linn, Polk, and Benton Counties in Oregon. In addition, two experiments were conducted at the Hyslop Agronomy Farm in Benton County and the Jackson Agronomy Farm in Linn County. The calculated value of water is presented in Table C-15. Note that as the quantity of water applied to an acre increases, the marginal value of the water decreases.

Whittlesay and Allison[129] conducted a study to determine representative values for water used in Washington agriculture. The effects of crop rotation, water supply, efficiency of water use, crop prices, returns to other fixed factors, and production costs were examined. The marginal value of water ranged from less than $12/acre-foot to $60/acre foot. Regardless of the assumptions about efficiency in water application, crop prices, rotations, crop yields, or production costs, the derived water values were generally less than $60/acre-foot.

TABLE C-15

ESTIMATED DOLLAR VALUE OF IRRIGATION WATER IN THE WILLAMETTE VALLEY, OREGON IN 1963[128]

(in dollars per acre-foot)

Application Rate in Acre-Inches per Year	Field Corn		Bush Beans	
	Experimental Data	Farm Survey Data	Experimental Data	Farm Survey Data
2	16.23	2.28	134.88	9.70
4	13.46	1.25	73.12	5.10
6	10.72	.85	45.80	3.50
8	7.97	.64	29.47	2.68
10	5.20	.52	18.35	2.18
12	2.45	.44	--	1.84
14	--	.38	3.75	1.58
15	--	--	1.05	--

On the basis of the values derived in these studies, it is estimated that some quantity of effluent water would be in demand in the market at prices ranging between $10 and $50 per acre foot, depending on local climatic conditions and availability of natural water. To determine the quantity that might be taken, it is necessary to consider the water balance for specific locations.

The quantity of effluent water that could be used for irrigation would be the greatest in the southwest corner of the United States and decrease in each successive state to the north and east. While this is a general guide, it is important to consider each location specifically.

It is important to consider the value of replacing present irrigation waters with effluent water. Water quality requirements for irrigation waters are significantly different than those for drinking water, recreation, and fisheries use as detailed in Table C-16. Replacement of higher quality waters now being used for irrigation essentially produces a new or augmented supply of high quality water. This in turn increases the value of the effluent water which makes the transfer possible. As in the case with irrigation water, the value of such a substitution will depend on the availability of waters of various qualities at specific locations.

TABLE C-16

EFFLUENT QUALITY VALUES FOR VARIOUS WATER USE CLASSIFICATIONS[131]

Parameter	Permissible Level (Surface Water for Public Water Supply)	Body Contact (Recreation)	Fisheries	Irrigation
Turbidity (JTU)	30	25	25	-
Color (units)	15	-	-	-
pH (units)	6.0-8.5	6.5-8.3	6.5-9.0	-
Total Residue (mg/l)	1000	-	-	-
Filtrable Residue (mg/l)	500	-	-	-
COD (mg/l)	4.0	-	-	100
TOC (mg/l)	10.0	-	-	-
CCE (mg/l)	0.1	-	-	-
MBAS (mg/l)	0.5	-	-	-
Coliform (counts/100 ml)	10,000	1,000	5,000	5,000
Fecal Coliform (counts/100 ml)	2,000	200	1,000	1,000
Total Dissolved Solids (mg/l)	<500	500	240	-
Oil & Grease (mg/l)	.05	-	-	-
Ammonia (mg/l N)	0.05	1.0	1.0	-
Hardness (mg/l $CaCO_3$)	250	-	-	-
Nitrates (mg/l N)	2.0-4.0	-	-	-
Phosphorus (mg/l)	0.1	-	-	-*

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* Nutrients may be beneficial to growth

There is also some question as to the magnitude of the value of nutrients in wastewater treatment plant effluents which can be beneficial to growth. Clearly, the ammonia nitrogen and phosphates present in such water has some fertilizer potential. Typical medium strength domestic sewage enters the wastewater treatment plant with 40 mg/l total nitrogen and 15 mg/l total phosphate. The fraction of these converted to available ammonia and soluble phosphates will depend greatly on the types of pretreatment employed at an individual plant. If primary clarification is the only treatment available, the effluent water will contain approximately 32 mg/l nitrogen and 14 mg/l phosphorus. Greater degrees of treatment will result in lower levels of nutrients in the effluent water.

An acre foot of water with 32 mg/l nitrogen and 14 mg/l phosphate contains a total of 83.4 pounds of nitrogen and 4.0 pounds of phosphorus. At the quoted prices of $99 and $393 per ton of nitrogen and phosphorus, respectively, the nutrients in the water would add a total of $6.88 to the value of an acre foot of water. Cantrell, et al.,[139] determined fertilizer value in Louisiana effluents to be $17.50 per acre foot.

Such a system represents long term, low level introduction of nutrients. This is preferrable to a single bulk loading as is typical with commercial fertilizer use. Henkelekian,[132] in studying wastewater irrigation in Israel, found that the growth increases due to available nutrients more than make up for growth inhibition which might have resulted from increased salinity. The benefits of available nutrients in effluent waters have also been substantiated by other authors.[119,134-137]

At irrigation rate of 40-48 inches per year, the nitrogen in sewage effluents would exceed requirements for most crops, and the phosphorus would be near optimal. If effluent is applied at greater rates in an attempt to treat more wastes on less land, nitrogen saturation becomes a concern with subsequent loss of nitrate to groundwaters at unacceptable levels. This situation can be controlled with adequate monitoring of nitrogen levels applied and use of low nutrient dilution water when necessary.

Use of effluent waters for irrigation involves some of the same risks as land spreading of sewage sludges. Disinfection is required to minimize the spread of pathogenic organisms.[1] Heavy metals may also be a problem though present in dilute concentrations. Rohde[133] reports that after 100 years of sewage farm operation at high application rates, some of the soil at the Paris and Berlin farms began to show marked decreases in productivity. Analysis of the soils revealed exceptionally high levels of copper and zinc.[133] Boron may also damage plant growth due to its high phytotoxicity. Most plants are sensitive to boron in the parts per million range. The presence of this metal from borax formulated detergents could inhibit sewage irrigation projects. These considerations suggest both the need for adequate characterization of effluents proposed for spray irrigation, and the fact that spray irrigation may be limited to finite periods of time after which use of metal free water would be necessitated.

TECHNOLOGICAL CHANGE

As stated earlier, changes in technology which result in easier handling and more efficient utilization of the products of a sewage treatment facility could increase their value by lowering the costs of application and minimizing aesthetic objections. For example, about 65 percent of the available effluent water in Israel in 1967 was reused. This percentage is likely to increase in the future. Yet, it is reported that farmers would prefer not to have to irrigate with effluent water.[126] In interviews with scientists from the University of Illinois and the Chicago Metropolitan Sanitary District, it was stated that considerable resistance is likely to occur in projects to irrigate with effluent water. With the design and use of equipment which results in less objectionable methods of handling effluent water, the value of a given quantity should increase.

In order to determine the potential for technological change, Battelle-Northwest surveyed fifty-three firms that manufacture components used in irrigated agriculture. The industry is acutely aware of a growing interest in effluent irrigation and subsequently has begun to address itself to that market. Valmont Industries expects to see center pivot equipment modified to handle streams with up to six percent solids. (Such a stream would be typical of a gravity thickened sludge.)

They state that such a design has not been tried to date, but the concepts are proven and quite simple. It is their opinion that the only reason for not using this equipment is the lack of available material in a geographic area where they could test their equipment.

McDowell Manufacturing Company has designed and developed equipment specifically for the spraying of waste effluents. They are attempting to market their system nationally.

Drainguard material which is manufactured by Advanced Drainage Systems, Incorporated, is being used for drainage water systems on the Muskegon County wastewater system. Advanced Drainage Systems is presently experimenting with a corrugated tube design that might be more suitable than their existing material for underground irrigation with effluent water.

The equipment of Western Oilfields Supply Company (Rain for Rent) has been used with some success on sewage disposal jobs where the effluent is of high quality and the solids are removed. Examples of this use as stated by a representatative of the firm are:

- Escondido, California - 80 acres of solid set on pasture; 300,000 gpd of high quality effluent from the city's municipal treatment plant.
- Salinas, California - Mission Hill Water Company spread runoff from cattle feedlots.
- Woodland, California - Cannery wastewater spread on alfalfa.
- Nampa, Idaho - Treated municipal effluent spread on alfalfa.
- Arizona - Treated municipal effluent used for compaction on highway construction jobs.

The Lockwood Corporation has an ongoing program for the development of equipment designed specifically to apply effluent water to land. They have been awarded a contract to furnish fifty-seven center pivot machines to the Muskegon County Wastewater System. Several modifications in the design of machines which were first designed to apply natural water were necessary. Machines designed solely for the application of natural water generally operate less than 1,000 hours per year. The machines to be used in Muskegon were designed to operate for over 4,000 hours. Effluent water will be applied at a rate of four inches per hour. In order to reduce the aerosol effect and the potential for wind drift, pressure at the nozzle was reduced from 70 psi to 3-5 psi. The spray bar was designed so that it could be raised and lowered. The result of these design changes was an increase in the coefficient of uniformity to over 90.

From these observations of the irrigation equipment industry, it can be concluded that there is active interest in the design, testing, and marketing of equipment suitable for handling effluent water and liquid sewage sludges in a way that is reducing objectionable elements of handling. As the use of this equipment becomes more common, the demand for effluent water can be expected to increase.